

Application of the Bighorn Sheep Risk of Contact Model on the Okanogan-Wenatchee National Forest

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INTRODUCTION

The sustainability of wild sheep populations and continued domestic grazing on publicly managed lands is a complex wildlife and range management issue. Domestic sheep have the potential to interact with wild sheep and spread fatal pneumonia to bighorn sheep which can result in herd die-offs (Jessup 1985, George et al. 2008, Lawrence et al. 2010). In 2013 the Okanogan-Wenatchee National Forest (OWNF) initiated a preliminary analysis of the potential for three bighorn sheep herds to contact a domestic sheep allotment located on national forest lands. This preliminary analysis was done in cooperation with the Washington Department of Fish and Wildlife (WDFW), Washington Department of Natural Resources and the Yakama Nation. Those results were then used to examine the potential for disease transmission based on assumptions developed in the risk analysis developed on the Payette National Forest (USFS 2010). The Okanogan-Wenatchee National Forest (OWNF) engaged WCSI to perform the Risk of Contact Analysis for all bighorn sheep herds currently located on or near (within 35km) the Forest with the most recent data and tools available, including those bighorn herds that do not have GPS location information (Figure 1). This analysis builds upon the work done previously by the OWNF.

We incorporated direction provided by the USFS-Washington Office (August 19, 2011) and conducted the analysis with the *Bighorn Sheep Risk of Contact Tool* (v2), developed by O'Brien et al (2014) and the FS/BLM Bighorn Sheep Working Group (2015). The *Bighorn Sheep Risk of Contact Tool* (v2) models the probability that foraging bighorn sheep will leave their home range to reach domestic grazing allotments and return. It is based on a combination of habitat suitability, distance of the allotment from the bighorn sheep herd home range, and herd composition. The Risk of Contact Tool does not model interactions with domestic sheep occupying those allotments and the presence or absence of domestic sheep in an allotment does not influence the modeled probability that bighorn sheep will reach that allotment (FS/BLM 2015). The development of the model was based on an extensive telemetry set from the Hells Canyon area bighorn sheep herds and subsequent habitat use and foray modeling.

METHODS

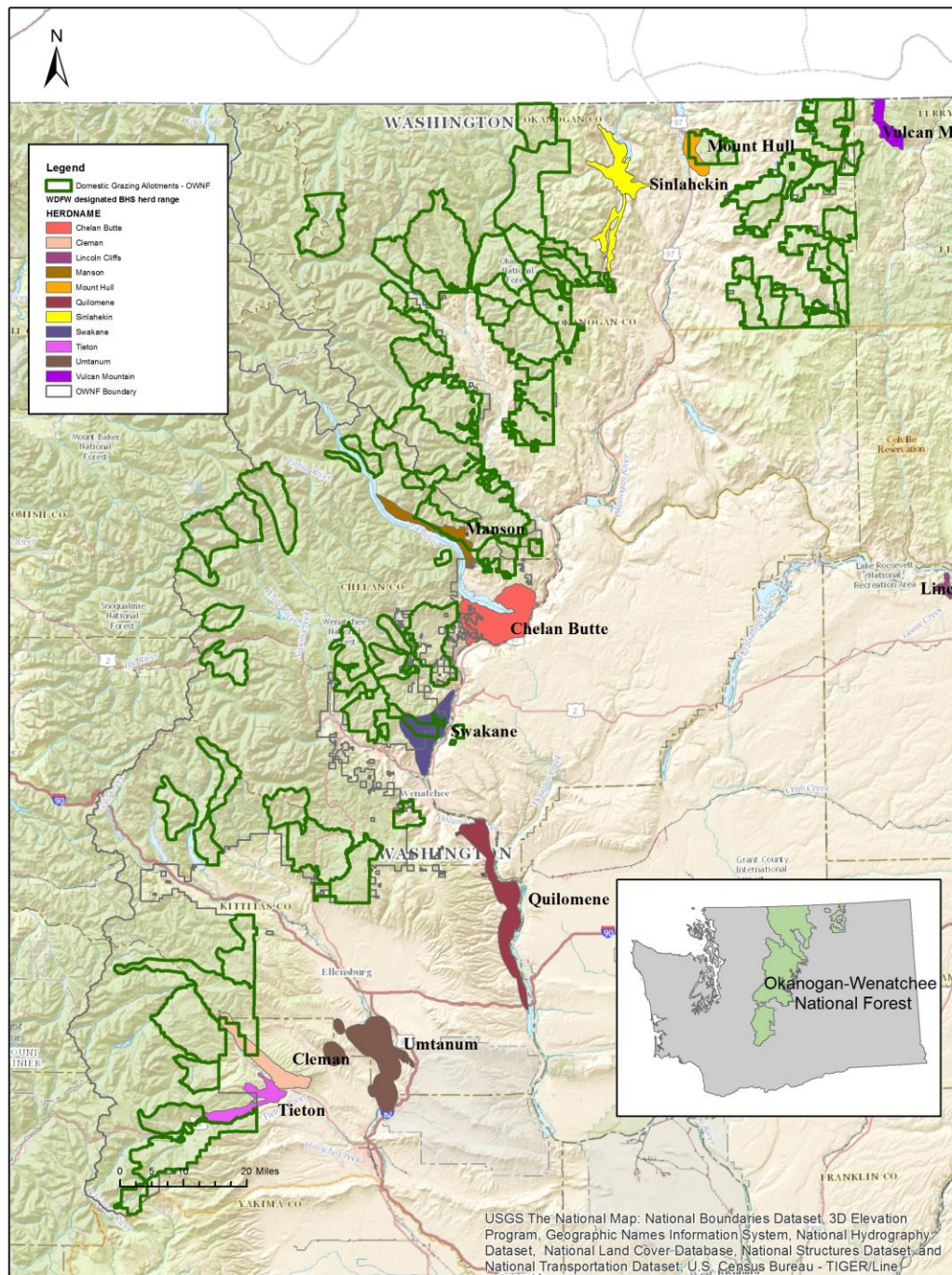
The Bighorn Sheep Risk of Contact Tool is a software program that incorporates data on bighorn sheep, domestic sheep, habitat and allotments to estimate a rate of contact. The Risk of Contact Tool consists of three main components: 1) Home Range Estimation, 2) Foray Analysis and 3) Contact Analysis. To parameterize each component we used site specific data when available and default values when site specific data were unavailable. Detailed information on model development and components may be found in O'Brien et al (2014) and the Risk of Contact Tool User Guide (FS/BLM 2015). The analysis area included all portions of the Okanogan-Wenatchee National Forest that were located within 35km of a bighorn sheep herd (Fig 1).

Home Range

WDFW began recording GPS telemetry data for bighorn sheep on the OWNF in the spring of 2009. These data allowed for calculation of a summer Core Herd Home Range (CHHR) for use in subsequent analyses for several of the herds (Table 1a and 1b). For this analysis "summer" is defined as May 15-Sept 15 to cover the current season of domestic sheep grazing use on Forest Service lands.

When telemetry data were available we estimated 95% contour CHHRs with the default reference estimator (h_{ref}), which is consistent with the foray and distance distributions and guidance in the Risk of Contact Tool. The 95% contour and reference bandwidth estimator are both commonly used in wildlife studies to define individual and population-level home ranges (Worton 1989).

Figure 1. Bighorn sheep herd ranges and domestic grazing allotments on the Okanogan-Wenatchee National Forest.



WDFW also created another estimate of core herd home ranges for each bighorn herd based on known bighorn activity and observations. Although the risk of contact model was designed to be robust to small changes in home range boundaries, the WDFW ranges were also used to run an alternative version of the analysis or when specific telemetry location data were not available. For this analysis the core herd home range derived with telemetry data is referred to as Telemetry CHHR while the core herd home range derived with WDFW observations is referred to as WDFW CHHR. The Tieton bighorn herd experienced an all-age die-off in the spring of 2013. The most recent data available for the Tieton herd were from 2010-2013, prior to the die-off and subsequent herd removal. As such, the results presented here only represent hypothetical results based on the previous bighorn herd.

Table 1a. Herd composition of bighorn sheep herds specific to the Okanogan-Wenatchee National Forest used in the risk of contact assessment. Data were provided by the Washington Department of Fish and Wildlife.

Herd	Total herd estimate (adults)	% ewes	% rams	Telemetry data used to calculate core herd home range?
Chelan Butte	125	64	36	Telemetry and observational.*
Cleman Mountain	154	67	33	Yes
Mt. Hull	95	57	43	No
Manson	91	73	27	Yes
Quilomene	68	63	37	Yes
Sinlahekin	46	90	10	Yes
Swakane	108	57	43	Yes
Tieton	99	81	19	Yes
Umtanum	229	74	26	No
Vulcan	25	60	40	No

*Sample sizes precluded calculation of individual home ranges.

Table 1b. Composition of bighorn sheep herd telemetry or observational data used in the risk of contact assessment.

Herd	Years data collected	GPS	Survey/ Observation	Number & Sex of Individuals
Chelan Butte	2005-2012		x	both rams and ewes*
Cleman Mountain	2010-2013	x		5 individuals (3 rams, 2 ewes)
Manson	2009-2010	x		1 ram, 3 ewes
	2014-2015	x		12 individuals
Quilomene	2003-2009		x	both rams and ewes
	2012-2013	x		1 individual
Sinlahekin	2010-2013	x		7 rams, 14 ewes
	2014-2015	x		unknown
Swakane	2012-2013	x		4 individuals
	2009-2010	x		1 ram, 3 ewes
Tieton	2010-2012	x		4 individuals (3 rams, 1 ewe)

*no individual home ranges

Foray Analysis

Habitat

The habitat component of the Risk of Contact Tool includes a habitat classification and habitat preference data. The classification is composed of three classes: habitat, connectivity area and non-habitat. A bighorn sheep habitat map was developed based on those habitat characteristics selected for by bighorns, such as forage, escape terrain and horizontal visibility (Valdez and Krausmann 1999, O'Brien et al 2014), that contribute to stationary or positive population growth (Wisdom et al. 2000, USFS 2010). The habitat map was initially developed by the Hells Canyon Initiative and refined by the Payette NF (USFS 2010) and O'Brien et al (2014). The primary components of the bighorn sheep habitat classification consist of: 1) suitable vegetation to provide forage, 2) suitable access to escape terrain, and 3) sufficient horizontal visibility with no vegetation or vegetation types with canopy cover <30%. Connectivity between areas of habitat is also important to population persistence. Connectivity was mapped as those areas that do not fulfill the definition of habitat but are located within 350m of habitat or within 525m if located between two patches of habitat (O'Brien et al. 2014). The remainder was classified as non-habitat. Detailed descriptions of the habitat components and models are available in O'Brien et al (2014). Through preliminary analysis and discussion the OOWNF, WDFW and Yakama Nation agreed that the habitat maps were likely accurate and sufficient for use in the risk of contact model.

Relative habitat preference was based on a resource selection function developed with the Hells Canyon dataset (O'Brien et al. 2014). The default values (Table 2) suggest that a given acre of habitat is nearly six times more likely to be occupied by a bighorn sheep than the same area of connectivity habitat, and 35 times more likely than non-habitat (FS/BLM 2015).

Forays

A foray is defined as a bighorn sheep leaving its CHHR and then returning. We used the default summer foray probabilities and distributions for rams and ewes as defined in the Risk of Contact Tool (FS/BLM 2015). Thirty-five kilometers was the maximum observed ram foray distance used to develop the Risk of Contact Tool and was the limit on the analysis area (O'Brien et al. 2014). Only allotments within 35km of a CHHR were considered in this analysis.

Contact Analysis

Domestic Grazing Allotments

We used the OOWNF map of active and vacant domestic grazing allotments (version March 2014). Although the main goal of this assessment was to examine risk of contact with domestic sheep allotments, we ran the analysis with all existing allotments, regardless of whether they were currently occupied, in order to inform decisions on possible alternatives to existing domestic sheep allotments. We also modified one active sheep allotment (Naches) at the request of the OOWNF to provide an example of potential alternative analyses. The original Naches allotment was divided into two parts: Naches North and Naches South, based on a description provided by the OOWNF (Figure 2).

Bighorn Sheep Herd Size

The estimated risk of contact is sensitive to the size of the bighorn sheep herd (e.g., as herd size increases so does the risk of contact). Herd numbers were provided by WDFW (WDFW 2014).

Table 2. The values or source used for each parameter within the *Bighorn Sheep Risk of Contact Tool* (v2). Changing the default values directly affects estimated probabilities and rates of contact. We used default values unless WDFW provided site specific information regarding bighorn sheep.

Risk of Contact Tool Component	Parameter	Value	Default? Y/N
Home Range	Core Herd Home Range	Developed CHHR with telemetry and/or used the range delimited by WDFW	N
	Minimum points per animal	21	Y – based on suggested value in user guide (FS/BLM 2015)
	Bandwidth estimator	h_{ref}	Y
	Percent of h_{ref}	100	Y
	Max Isopleth quantile	95	Y
Foray Analysis	Habitat Layer Preference: Habitat	1	Y
	Habitat Layer Preference: Connectivity	0.177	Y
	Habitat Layer Preference: Non-habitat	0.029	Y
	Ram Distance Distribution	Provided with Risk of Contact Tool	Y
	Ewe Distance Distribution	Provided with Risk of Contact Tool	Y
Contact Analysis	Allotment Layer	Polygon shapefile	N – provided by OWN
	Herd size	Variable	N – provided by WDFW. See Table 1.
	Herd sex ratio	Variable	N – provided by WDFW. See Table 1.
	Foray probability	Rams = 0.141, Ewes = 0.015	Y

Contact Analysis Results

The *Bighorn Sheep Risk of Contact Tool* (v2) provided an estimated risk of contact, between bighorn sheep and domestic grazing allotments, for bighorn sheep herds on or within 35km of the Okanogan-Wenatchee National Forest. The results of the output were defined as follows:

- Type: C=cattle, S=sheep, H=horse
- Status: active, vacant
- Single_Ram: Annual/seasonal probability that any given ram will foray outside its CHHR and contact this allotment.
- Single_Ewe: Annual/seasonal probability that any given ewe will foray outside its CHHR and contact this allotment.
- All_Rams: Average *number* of rams expected to foray outside the CHHR and contact this allotment each year/season.
- All_Ewes: Average *number* of ewes expected to foray outside the CHHR and contact this allotment each year/season.
- All_Herd: Average number of adult bighorn sheep (rams plus ewes) expected to foray outside the CHHR and contact this allotment each year/season.

Disease Analysis

Although it may not directly equate to interactions between bighorn and domestic sheep, the Risk of Contact Model provides outcomes that describe contact rates between bighorn sheep and allotment boundaries. The Risk of Contact Model is a starting point for quantifying one element that may influence the viability of bighorn sheep populations. And while there is no research to document and calculate estimates of allotment contact and subsequent domestic sheep interactions, there is documented evidence that these interactions can transmit disease (USFS 2010). When bighorn sheep die-offs occur, there is substantial immediate mortality and population recovery is hindered by poor lamb recruitment, potentially for many years, ultimately leading to declining populations.

“Although there is no guidance on the number of decades required to recover from a disease outbreak, observations of herds that have experienced pneumonic events indicate it likely requires several. Given the severity of respiratory die-offs and the potential link to domestic sheep as a causal factor in outbreaks, management scenarios should allow for long periods of time without interspecies contact. Population recovery is unlikely where interspecies contact, potentially resulting in disease transmission and subsequent disease outbreaks, occur within a few decades of each other” (FS/BLM 2015 page H-8).

Although empirical data are currently lacking on recommended outbreak intervals, a moderate level of outbreak events (ie. 0.25), which would lead to an average outbreak period of 50 years, has been suggested as a potential benchmark to ensure population persistence (FS/BLM 2015). The Bighorn Working Group (FS/BLM 2015) has suggested that results of the Risk of Contact Tool may be interpreted as follows:

“Given the potential severity of die-off resulting from interspecies contact we recommend management scenarios that allow for disease free intervals of at least 50 years. If we assume a moderate probability of a contact with an allotment resulting in an interspecies contact that will result in a disease transmission outbreak event (0.25), then we would need to see a rate of contact of <0.08 contacts per year (or less than 0.8 contacts per decade).”

Using the above interpretation we summarized annual contact rates for each herd and calculated the likelihood of a disease outbreak in 50 years.

RESULTS and DISCUSSION

The Rate of Contact for each of the 10 bighorn herds considered in this analysis varied due to proximity to domestic grazing allotments, habitat configuration and herd composition. The Rate of Contact results for the Telemetry CHHR and WDFW CHHR varied depending on size and configuration of the home range. Changes in the shape of the home range, and not just the overall size of the area, increased and decreased contact rates as well. If a bighorn sheep home range and an allotment intersected, the risk of contact estimate could not be calculated because the model estimated the risk of a bighorn sheep leaving its home range and contacting an allotment (i.e. the event already occurred). The following summary describes overall results for each bighorn sheep herd (for both telemetry and WDFW derived CHHRs) relative to domestic sheep grazing allotments. Complete results, including maps, for each bighorn herd relative to both CHHRs and all sheep, cattle and horse allotments are provided in Appendix S1.

Only seven bighorn sheep herds were located within 35km of an active sheep grazing allotment: Chelan Butte, Cleman Mountain, Manson, Quilomene, Swakane, Tieton and Umtanum (Table 3). Five herds exceeded the suggested risk threshold of 0.08 contacts per year with at least one active sheep allotment: Chelan Butte, Cleman Mountain, Swakane, Tieton and Umtanum.

Contact rates for the Cleman Mountain herd ranged from 0.27 – 0.68 contacts per year for active sheep allotments. Contact rates for the Umtanum herd and the prior Tieton herd ranged from <0.01 – 0.26 contacts

per year. Contact rates for the Swakane herd ranged from <0.01 – 0.84 contacts per year. Contact rates for the Chelan Butte herd ranged from 0.01 – 0.12 contacts per year. Contact rates for the Manson and Quilomene herds ranged from <0.01 – 0.01 contacts per year.

Table 3. Estimated probabilities and annual contact rates for the bighorn sheep herds relative to existing **sheep** allotments on the Okanogan-Wenatchee National Forest. Probabilities and contact rates were estimated for a telemetry derived core herd home range (Telemetry CHHR) and an observed core herd home range delimited by WDFW biologists (WDFW CHHR). All_Herd Contact Rates ≥ 0.08 contacts/year exceeded the suggested threshold to limit disease outbreak intervals recommended by the Bighorn Working Group (FS/BLM 2015).

Telemetry derived core herd home range (Telemetry CHHR)

Bighorn Sheep Herd	Active Sheep Allotment	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Chelan Butte	Mosquito Ridge	<0.01	<0.01	0.10	0.01	0.11
	Switchback	<0.01	<0.01	0.02	<0.01	0.02
	Limekiln-Sugarloaf	<0.01	<0.01	0.02	<0.01	0.02
	Eagle-Blagg	<0.01	<0.01	0.01	<0.01	0.01
Cleman Mountain	Rattlesnake	0.01	<0.01	0.65	0.03	0.68
	Manastash	0.01	<0.01	0.26	0.01	0.27
	Naches					*intersects
	Nile					*intersects
Manson	Mosquito Ridge	<0.01	<0.01	0.01	<0.01	0.01
	Limekiln-Sugarloaf	0.00	<0.01	<0.01	<0.01	<0.01
Quilomene	Eagle-Blagg	<0.01	<0.01	<0.01	<0.01	0.01
	Swauk	<0.01	<0.01	<0.01	<0.01	<0.01
Swakane	Eagle-Blagg	0.02	<0.01	0.81	0.03	0.84
	Mosquito Ridge	<0.01	<0.01	0.21	0.01	0.22
	Switchback	<0.01	<0.01	0.11	<0.01	0.11
	Limekiln-Sugarloaf	<0.01	<0.01	0.05	<0.01	0.05
	Swauk	<0.01	<0.01	0.01	<0.01	0.01
Tieton	Naches	0.01	<0.01	0.16	0.02	0.18
	Rattlesnake	0.01	<0.01	0.15	0.02	0.17
	Nile	0.01	<0.01	0.10	0.01	0.12
	Manastash	<0.01	<0.01	0.01	<0.01	0.01
Umtanum	Naches	<0.01	<0.01	0.11	0.02	0.13
	Manastash	<0.01	<0.01	0.01	<0.01	0.02
	Nile	<0.01	<0.01	0.01	<0.01	0.01
	Rattlesnake	<0.01	<0.01	<0.01	<0.01	<0.01

WDFW derived core home range (WDFW CHHR)

Chelan Butte	Mosquito Ridge	<0.01	<0.01	0.11	0.01	0.12
	Switchback	<0.01	<0.01	0.03	<0.01	0.03
	Limekiln-Sugarloaf	<0.01	<0.01	0.03	<0.01	0.03

	Eagle-Blagg	<0.01	<0.01	0.02	<0.01	0.02
Cleman Mountain	Rattlesnake	0.01	<0.01	0.38	0.02	0.40
	Manastash	0.01	<0.01	0.29	0.01	0.31
	Naches					*intersects
	Nile					*intersects
Manson	Mosquito Ridge	<0.01	<0.01	0.01	<0.01	0.01
	Limekiln-Sugarloaf	<0.01	<0.01	<0.01	<0.01	<0.01
Quilomene	Swauk	<0.01	<0.01	0.01	<0.01	0.01
	Eagle-Blagg	<0.01	<0.01	<0.01	<0.01	<0.01
Swakane	Eagle-Blagg	0.02	<0.01	0.74	0.03	0.77
	Mosquito Ridge	0.01	<0.01	0.23	0.01	0.24
	Switchback	<0.01	<0.01	0.13	<0.01	0.13
	Limekiln-Sugarloaf	<0.01	<0.01	0.06	<0.01	0.06
	Swauk	<0.01	<0.01	0.01	<0.01	0.01
Tieton	Rattlesnake	0.01	<0.01	0.20	0.02	0.22
	Naches	0.01	<0.01	0.17	0.04	0.21
	Nile	0.01	<0.01	0.11	0.01	0.12
	Manastash	<0.01	<0.01	0.01	<0.01	0.01
Umtanum	Naches	<0.01	<0.01	0.24	0.02	0.26
	Nile	<0.01	<0.01	0.03	0.01	0.04
	Manastash	<0.01	<0.01	0.04	<0.01	0.04
	Rattlesnake	<0.01	<0.01	0.03	0.01	0.04
	Swauk	<0.01	<0.01	<0.01	<0.01	<0.01

Likelihood of Disease Transmission

The annual contact rates allowed us to identify which herds may be at risk from which allotments based on suggested risk thresholds (FS/BLM 2015). These results suggested that several of the bighorn sheep herds may be at risk for a disease outbreak within 50 years given the current proximity to active domestic sheep grazing allotments. If we examined those bighorn sheep herds that were within 35km of an active sheep allotment we found the Chelan Butte, Cleman Mountain, Swakane, Tieton and Umtanum bighorn sheep herds may be expected to experience a disease outbreak within 50 years (Table 4). In contrast, the Manson and Quilomene bighorn sheep herds would not be expected to experience a disease outbreak within 50 years.

The Risk of Contact Tool provided a refined and rigorous method for analyzing one important element that may contribute to potential disease outbreaks as a result of bighorn and domestic sheep interaction. The results of our analysis suggested several bighorn sheep herds on/near the Okanogan-Wenatchee National Forest may be at risk. The Cleman Mountain and Tieton bighorn sheep herd home ranges overlap active sheep allotments and thereby might be considered a top priority for updating the NEPA analysis, including the qualitative information about disease transmission and herd management this Risk of Contact Tool did not address. Additionally, because the results indicated the Chelan Butte, Cleman Mountain, Swakane, Tieton and Umtanum bighorn sheep herds may be expected to experience a disease outbreak within 50 years, they would be another possible priority for updating the NEPA analysis, including the qualitative information about disease transmission and herd management this Risk of Contact Tool did not address.

Table 4. Summary of the likelihood of a disease outbreak (as defined by the Bighorn Sheep Working Group, FS/BLM 2015) occurring within each of the different bighorn sheep herds on or within 35km of the Okanogan-Wenatchee National Forest, assuming contact with an **active** sheep allotment. All_Herd = Average number of adult bighorn sheep (rams plus ewes) expected to foray outside the core herd home range and contact allotment each year/season.

HERD	RANGE	Sheep Allotment	All_Herd	Number of contacts per decade	Number of contacts per 50 years	Outbreak expected in 50 years?
CHELAN BUTTE	Telemetry CHHR	Mosquito Ridge	0.11	1.1	5.5	Yes
		Limekiln-Sugarloaf	0.02	0.2	1.0	No
		Switchback	0.02	0.2	1.2	No
		Eagle-Blagg	0.01	0.1	0.6	No
	WDFW CHHR	Mosquito Ridge	0.12	1.2	5.9	Yes
		Limekiln-Sugarloaf	0.03	0.3	1.7	No
		Switchback	0.03	0.3	1.5	No
		Eagle-Blagg	0.02	0.2	1.1	No
CLEMAN MOUNTAIN	Telemetry CHHR	Rattlesnake	0.68	6.8	34.1	Yes
		<i>NachesNorth</i>	0.42	4.2	20.9	Yes
		Manastash	0.27	2.7	13.6	Yes
		Naches	*intersects	NA	NA	NA
		Nile	*intersects	NA	NA	NA
		<i>NachesSouth</i>	*intersects	NA	NA	NA
		Rattlesnake	0.4	4	19.9	Yes
		<i>NachesNorth</i>	0.37	3.7	18.5	Yes
		Manastash	0.31	3.1	15.3	Yes
		Naches	*intersects	NA	NA	NA
		Nile	*intersects	NA	NA	NA
		<i>NachesSouth</i>	*intersects	NA	NA	NA
MANSON	Telemetry CHHR	Mosquito Ridge	0.01	0.1	0.4	No
		Limekiln-Sugarloaf	<0.01	0.1	0.5	No
		Mosquito Ridge	0.01	0.1	0.6	No
		Limekiln-Sugarloaf	<0.01	0.1	0.5	No
QUILOMENE	Telemetry CHHR	Eagle-Blagg	0.01	0.1	0.3	No
		Swauk	<0.01	0.1	0.5	No
		Eagle-Blagg	<0.01	0.1	0.5	No
		Swauk	0.01	0.1	0.5	No
SWAKANE	Telemetry CHHR	Eagle-Blagg	0.84	8.4	42	Yes
		Mosquito Ridge	0.22	2.2	10.8	Yes
		Switchback	0.11	1.1	5.6	Yes
		Limekiln-Sugarloaf	0.05	0.5	2.4	No

		Swauk	0.01	0.1	0.4	No
	WDFW CHHR	Eagle-Blagg	0.77	7.7	38.5	Yes
		Mosquito Ridge	0.24	2.4	12.2	Yes
		Switchback	0.13	1.3	6.7	Yes
		Limekiln-Sugarloaf	0.06	0.6	3	No
		Swauk	0.01	0.1	0.6	No
TIETON	Telemetry CHHR	<i>NachesSouth</i>	0.19	1.9	9.6	Yes
		Naches	0.18	1.8	9.2	Yes
		Rattlesnake	0.17	1.7	8.4	Yes
		Nile	0.12	1.2	5.8	Yes
		<i>NachesNorth</i>	0.02	0.2	0.9	No
		Manastash	0.01	0.1	0.3	No
	WDFW CHHR	Naches	0.21	2.1	10.4	Yes
		<i>NachesSouth</i>	0.21	2.2	10.8	Yes
		<i>NachesNorth</i>	0.02	1.2	6.1	Yes
		Manastash	0.01	0.1	0.5	No
UMTANUM	WDFW CHHR	Naches	0.26	2.6	13	Yes
		<i>NachesSouth</i>	0.26	2.6	13	Yes
		Manastash	0.04	0.4	2	No
		Nile	0.04	0.4	2.1	No
		Rattlesnake	0.04	0.4	2	No
		Swauk	0.01	0.1	0.5	No
		<i>NachesNorth</i>	0.01	0.1	0.6	No

Results and Discussion cont.

As an example of an action that could be taken to decrease risk and to conduct a basic evaluation of the Risk of Contact Tools' ability to detect change, we examined the effect of changing allotment boundaries. For this scenario we only utilized the Telemetry CHHR. The Naches allotment was within 35km of the Umtanum and Tieton bighorn sheep herd ranges and intersected the Cleman Mountain herd range. The estimated Risk of Contact Rate with a single Naches allotment was 0.13 for the Umtanum herd and 0.18 for the Tieton herd. We altered the boundaries of the Naches allotment and created two hypothetical allotments: *Naches North* and *Naches South*. That did not change the risk for the Cleman Mountain herd: the Cleman Mountain CHHR still intersected the *Naches South* allotment and had a contact rate of 0.42 contacts per year with *Naches North*, resulting in an expected disease outbreak in 50 years. The Tieton herd was located farther to the southwest of the Naches allotment relative to the Cleman Mountain herd. Dividing the Naches allotment in two resulted in a decreased rate of contact for *Naches North*, to 0.02 contacts per year, but a marginal increase for *Naches South*, to 0.19 contacts per year. Thus, only *Naches South* would be expected to have a disease outbreak in 50 years, while *Naches North* would be below the 50 year threshold. The Umtanum bighorn herd was located northeast of both the Tieton and Cleman Mountain herds. The contact rate for the *Naches South* allotments remained at 0.13 contacts per year with an expected outbreak in 50 years. The *Naches North* allotment would have a decreased contact rate of 0.01 contacts per year and would not be expected to result in an outbreak. These results indicated that modifying allotment boundaries and subsequent grazing may be one way to decrease risk of contact.

We also examined the risk of contact with cattle and horse allotments, as well as allotments that are currently vacant. The contact rates varied considerably, but this information may be useful in identifying alternative grazing areas for the bighorn sheep herds that are currently at risk.

Additional Viability Components

The following items potentially contribute to the viability of bighorn sheep herds and may be considered for a complete assessment and potential modification of risk. The list is by no means exhaustive.

1. Use the model to evaluate relative suitability of modified or new allotments on the OWNF.
2. Consider risk of contact with domestic sheep occupying areas that are not administered by the OWNF.
3. Identify management practices with the goal of separation between domestic and bighorn sheep where necessary to provide for Forest-wide bighorn sheep viability. Examine how these practices affect the risk of contact values.
4. Identify obstacles on the landscape that may be preventing or reducing the risk of contact (i.e. wildlife fences) but are not currently incorporated into model.
5. Assess spatial and temporal overlap of bighorn sheep core herd home ranges with domestic sheep use areas and driveways.
6. Use the model to evaluate relative suitability of different potential bighorn sheep reintroduction sites in a landscape containing numerous private domestic sheep flocks.
7. Consider other elements that contribute to viability such as habitat suitability, risk of mortality from automobiles, population size in relation to genetic diversity, etc.
8. Consider impacts of human recreation activities within bighorn herd boundaries.

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Appendix S1. Complete results and maps for each bighorn herd relative to both CHHRs and all sheep, cattle and horse allotments.

Table S1a. Estimated probabilities and annual contact rates for the Chelan Butte bighorn sheep herd relative to existing **sheep** allotments on the Okanogan-Wenatchee National Forest. Probabilities and contact rates were estimated for a telemetry derived core herd home range (Telemetry CHHR) and an observed core herd home range delimited by WDFW biologists (WDFW CHHR).

**CHELAN BUTTE
TELEMETRY
CHHR**

Allotment	Type	Status	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Mosquito Ridge	S	ACTIVE	<0.01	<0.01	0.10	0.01	0.11
Limekiln-Sugarloaf	S	ACTIVE	<0.01	<0.01	0.02	<0.01	0.02
Switchback	S	ACTIVE	<0.01	<0.01	0.02	<0.01	0.02
Eagle-Blagg	S	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
WDFW CHHR							
Allotment	Type	Status	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Mosquito Ridge	S	ACTIVE	<0.01	<0.01	0.11	0.01	0.12
Limekiln-Sugarloaf	S	ACTIVE	<0.01	<0.01	0.03	<0.01	0.03
Switchback	S	ACTIVE	<0.01	<0.01	0.03	<0.01	0.03
Eagle-Blagg	S	ACTIVE	<0.01	<0.01	0.02	<0.01	0.02
Horsethief	S	VACANT	<0.01	<0.01	<0.01	<0.01	0.01

Table S1b. Estimated probabilities and annual contact rates for the Chelan Butte bighorn sheep herd relative to all existing allotments on the Okanogan-Wenatchee National Forest. This includes cattle, sheep, and horse as well as active and vacant allotments. Information is for illustrative purposes and demonstrates risk if allotments were converted to sheep grazing.

**TELEMETRY
CHHR**

Allotment	Type	Status	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Potato Creek	C	ACTIVE	0.03	<0.01	1.36	0.08	1.44
Alta Coulee	C	ACTIVE	0.02	<0.01	0.82	0.09	0.91
Union Valley	C	ACTIVE	0.01	<0.01	0.47	0.02	0.48
Hunter-McFarland	C	ACTIVE	0.01	<0.01	0.28	0.01	0.29
Antoine Creek	C	ACTIVE	<0.01	<0.01	0.17	0.01	0.18
McFarland	C	VACANT	<0.01	<0.01	0.16	0.01	0.17
Swakane	NA	VACANT	<0.01	<0.01	0.14	0.01	0.14
Mosquito Ridge	S	ACTIVE	<0.01	<0.01	0.10	0.01	0.11
Slide Ridge	NA	VACANT	<0.01	<0.01	0.05	<0.01	0.06
Upper Hay Canyon	NA	VACANT	<0.01	<0.01	0.02	<0.01	0.03
Hungry	C	ACTIVE	<0.01	<0.01	0.02	<0.01	0.02
Limekiln-Sugarloaf	S	ACTIVE	<0.01	<0.01	0.02	<0.01	0.02
Switchback	S	ACTIVE	<0.01	<0.01	0.02	<0.01	0.02

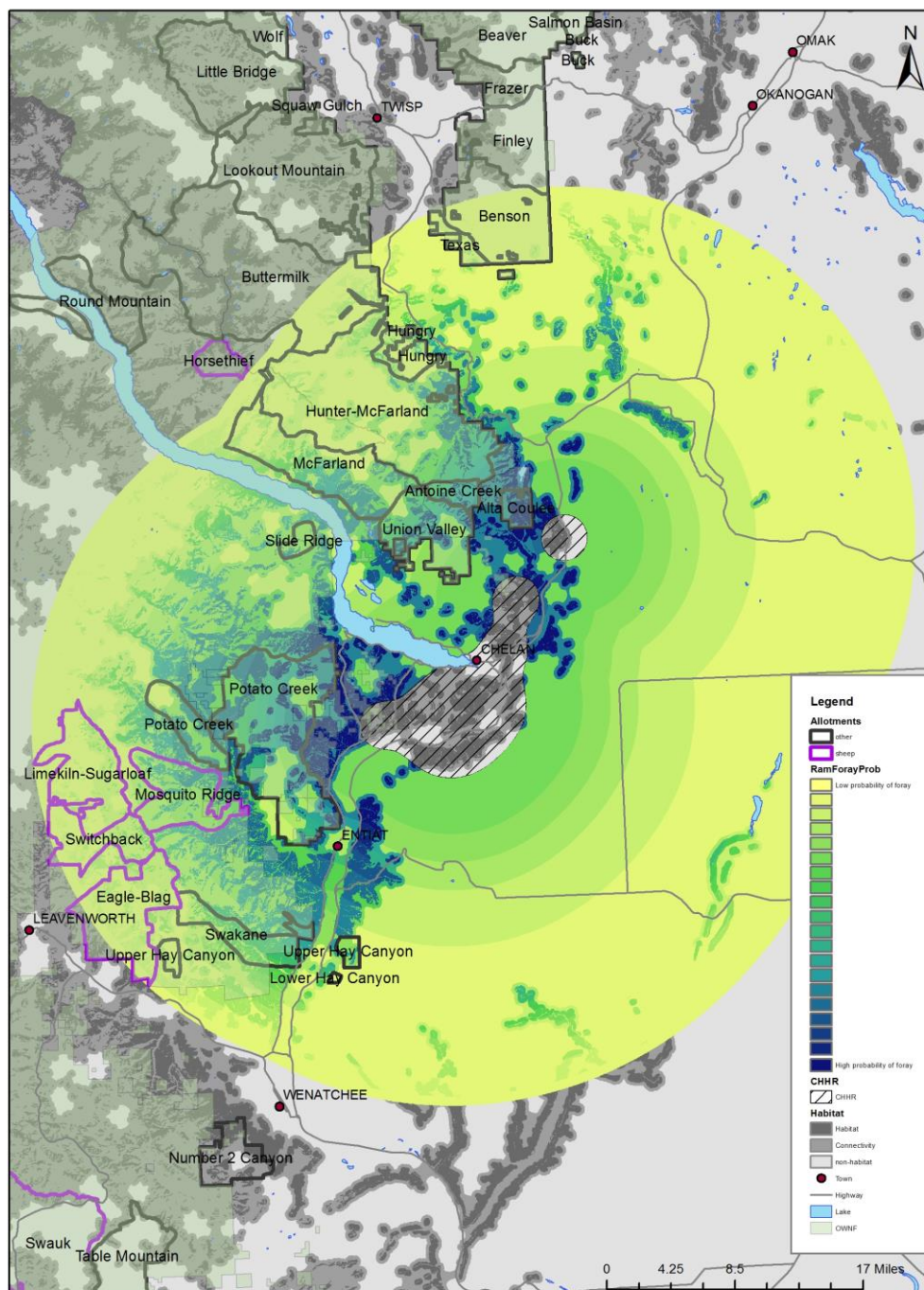
Buttermilk	NA	VACANT	<0.01	<0.01	0.01	<0.01	0.01
Eagle-Blagg	S	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Benson	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Finley	C	ACTIVE	<0.01	<0.01	0.00	<0.01	<0.01
Lookout Mountain	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Lower Hay Canyon	NA	VACANT	<0.01	<0.01	<0.01	<0.01	<0.01
Texas	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01

WDFW CHHR

Allotment	Type	Status	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Potato Creek	C	ACTIVE	0.03	<0.01	1.40	0.10	1.50
Union Valley	C	ACTIVE	0.01	<0.01	0.42	0.02	0.44
Alta Coulee	C	ACTIVE	0.01	<0.01	0.28	0.01	0.29
McFarland	C	VACANT	0.01	<0.01	0.27	0.02	0.28
Swakane	NA	VACANT	<0.01	<0.01	0.20	0.01	0.21
Hunter-McFarland	C	ACTIVE	<0.01	<0.01	0.17	0.01	0.18
Antoine Creek	C	ACTIVE	<0.01	<0.01	0.17	0.01	0.17
Slide Ridge	NA	VACANT	<0.01	<0.01	0.15	0.01	0.16
Mosquito Ridge	S	ACTIVE	<0.01	<0.01	0.11	0.01	0.12
Limekiln-Sugarloaf	S	ACTIVE	<0.01	<0.01	0.03	<0.01	0.03
Switchback	S	ACTIVE	<0.01	<0.01	0.03	<0.01	0.03
Eagle-Blagg	S	ACTIVE	<0.01	<0.01	0.02	<0.01	0.02
Upper Hay Canyon	NA	VACANT	<0.01	<0.01	0.02	<0.01	0.02
Buttermilk	NA	VACANT	<0.01	<0.01	0.01	<0.01	0.01
Horsethief	S	VACANT	<0.01	<0.01	<0.01	<0.01	0.01
Hungry	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Benson	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Lower Hay Canyon	NA	VACANT	<0.01	<0.01	<0.01	<0.01	<0.01

Figure S1. Spatial results generated with the *Bighorn Sheep Risk of Contact Tool* for the Chelan Butte bighorn sheep herd. The telemetry core herd home range and WDFW core herd home range for the Chelan Butte herd are presented in relation to the domestic grazing allotments, bighorn sheep habitat and foray probabilities for rams, within 35 km of the bighorn home ranges. Foray probability is displayed as concentric rings, with a light yellow indicating low probability of foray and increasing in shade to dark blue, indicating a high probability of foray.

Chelan Butte Telemetry CHHR



Chelan Butte WDFW CHHR

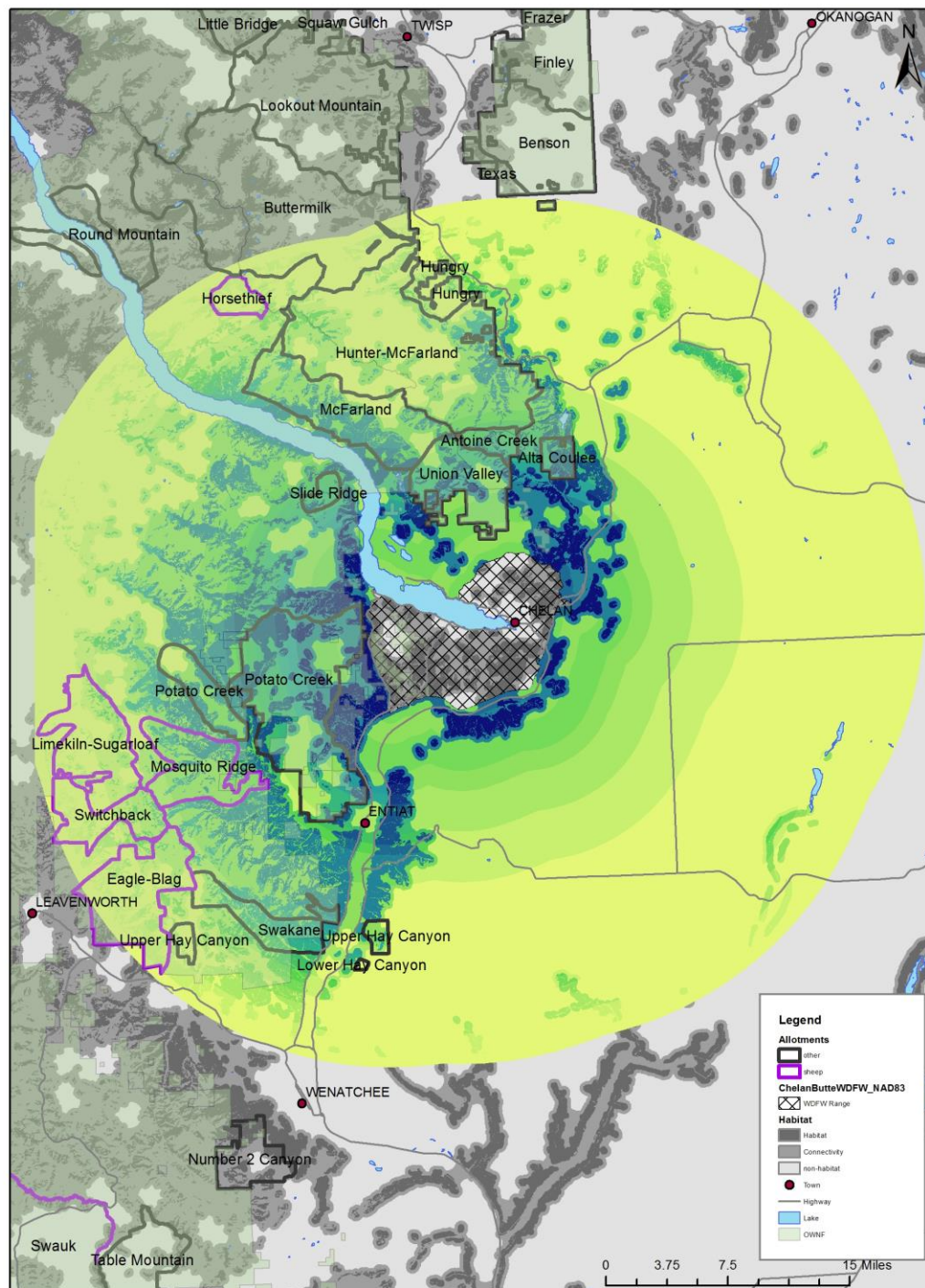


Table S2a. Estimated probabilities and annual contact rates for the Cleman Mountain bighorn sheep herd relative to existing **sheep** allotments on the Okanogan-Wenatchee National Forest. *NachesNorth* and *NachesSouth* refer to hypothetical modifications to the Naches allotment based on input from the OWNF. Probabilities and contact rates were estimated for a telemetry derived core herd home range (Telemetry CHHR) and an observed core herd home range delimited by WDFW biologists (WDFW CHHR).

**CLEMAN MOUNTAIN
TELEMETRY CHHR**

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Rattlesnake	S	ACTIVE	0.01	<0.01	0.65	0.03	0.68
<i>NachesNorth</i>	S	ACTIVE	0.01	<0.01	0.37	0.04	0.42
Manastash	S	ACTIVE	0.01	<0.01	0.26	0.01	0.27
Naches	S	ACTIVE					*intersects
Nile	S	ACTIVE					*intersects
<i>NachesSouth</i>	S	ACTIVE					*intersects

WDFW CHHR

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Rattlesnake	S	ACTIVE	0.01	<0.01	0.38	0.02	0.40
<i>NachesNorth</i>	S	ACTIVE	0.01	<0.01	0.33	0.04	0.37
Manastash	S	ACTIVE	0.01	<0.01	0.29	0.01	0.31
Naches	S	ACTIVE					*intersects
Nile	S	ACTIVE					*intersects
<i>NachesSouth</i>	S	ACTIVE					*intersects

* This allotment intersects the home range polygon and is therefore not included in the analysis.

Table S2b. Estimated probabilities and annual contact rates for the Cleman Mountain bighorn sheep herd relative to all existing allotments on the Okanogan-Wenatchee National Forest. This includes cattle, sheep, and horse as well as active and vacant allotments. Information is for illustrative purposes and demonstrates risk if allotments were converted to sheep grazing.

TELEMETRY CHHR

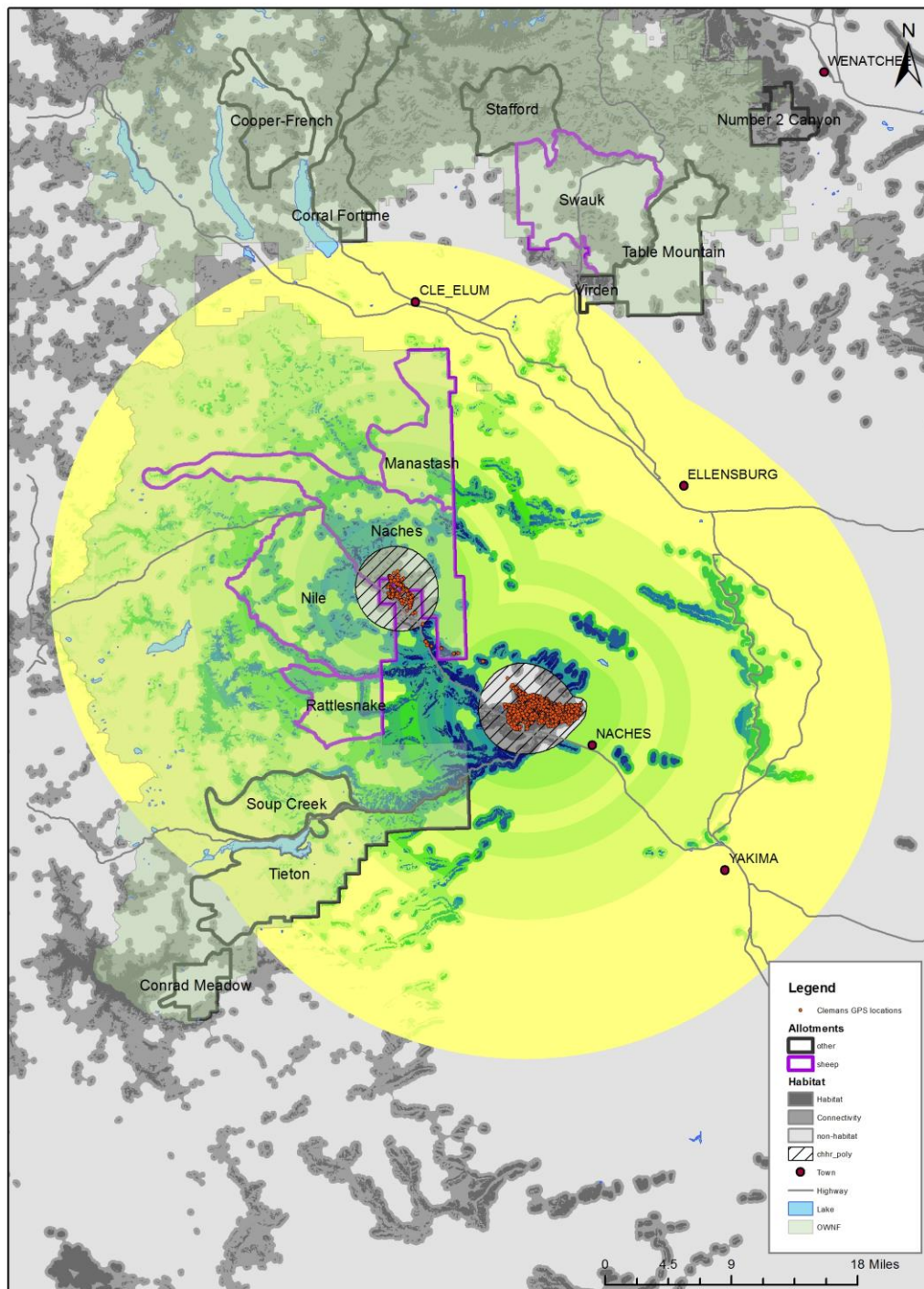
Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Rattlesnake	S	ACTIVE	0.01	<0.01	0.65	0.03	0.68
Manastash	S	ACTIVE	0.01	<0.01	0.26	0.01	0.27
Tieton	C	ACTIVE	<0.01	<0.01	0.17	0.01	0.19
Soup Creek	C	ACTIVE	<0.01	<0.01	0.15	0.01	0.16
Virden	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Naches	S	ACTIVE					*intersects
Nile	S	ACTIVE					*intersects

WDFW CHHR

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Rattlesnake	S	ACTIVE	0.01	<0.01	0.38	0.02	0.40
Manastash	S	ACTIVE	0.01	<0.01	0.29	0.01	0.31
Tieton	C	ACTIVE	<0.01	<0.01	0.16	0.01	0.17
Soup Creek	C	ACTIVE	<0.01	<0.01	0.10	0.01	0.11
Naches	S	ACTIVE					*intersects
Nile	S	ACTIVE					*intersects

Figure S2. Spatial results generated with the *Bighorn Sheep Risk of Contact Tool* for the Cleman Mountain bighorn sheep herd. The telemetry core herd home range and WDFW core herd home range for the Cleman Mountain herd are presented in relation to the domestic grazing allotments, bighorn sheep habitat and foray probabilities for rams, within 35 km of the bighorn home ranges. Foray probability is displayed as concentric rings, with a light yellow indicating low probability of foray and increasing in shade to dark blue, indicating a high probability of foray.

Cleman Mountain Telemetry CHHR



Cleman Mountain WDFW CHHR

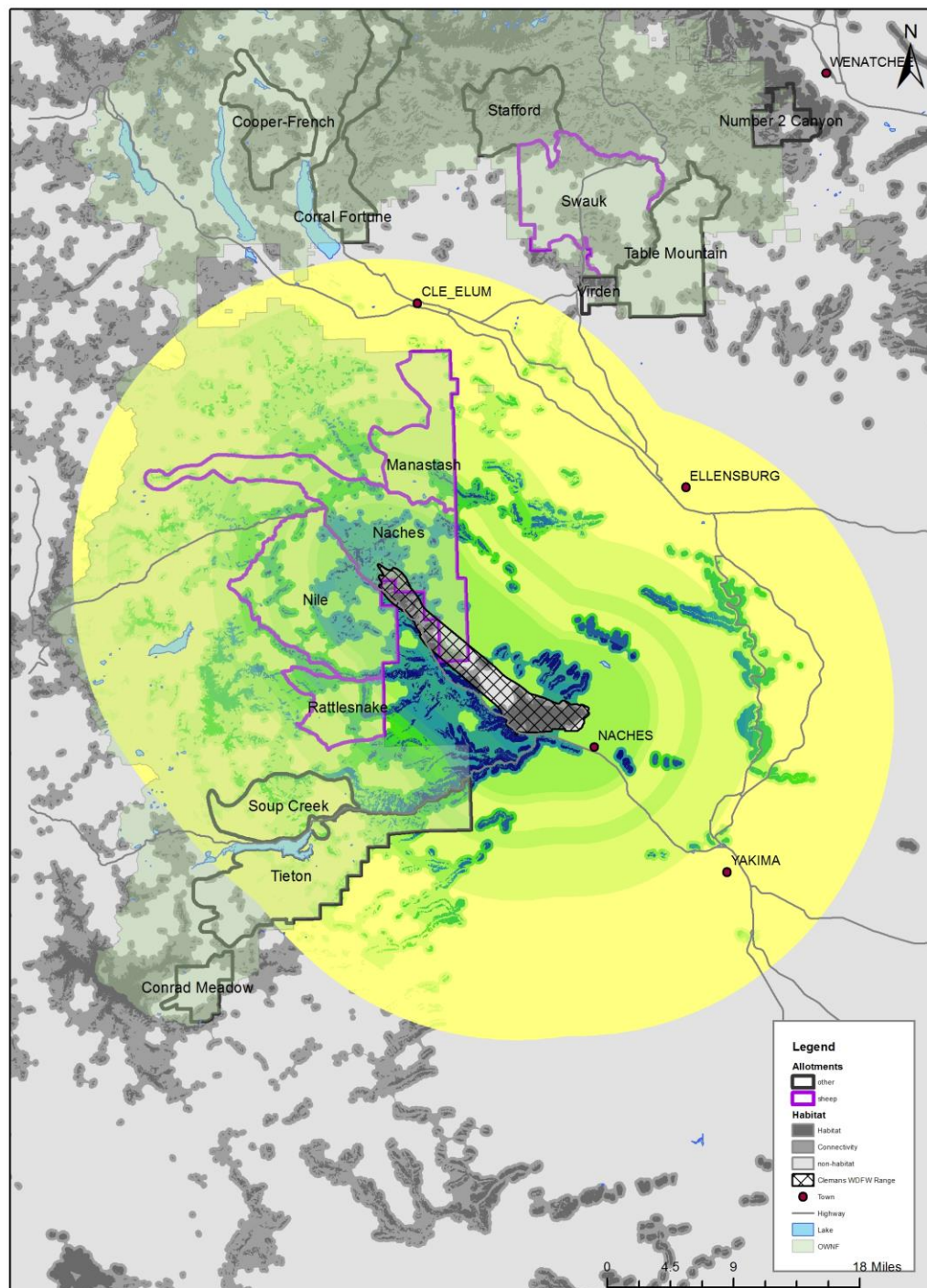


Table S3a. Estimated probabilities and annual contact rates for the Manson bighorn sheep herd relative to existing **sheep** allotments on the Okanogan-Wenatchee National Forest. Probabilities and contact rates were estimated for a telemetry derived core herd home range (Telemetry CHHR) and an observed core herd home range delimited by WDFW biologists (WDFW CHHR).

**MANSON
TELEMETRY
CHHR**

Allotment	Type	Status	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Horsethief	S	VACANT	0.01	<0.01	0.20	0.02	0.21
Mosquito Ridge	S	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Limekiln-Sugarloaf	S	ACTIVE	0.00	<0.01	<0.01	<0.01	<0.01

WDFW CHHR

Allotment	Type	Status	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Horsethief	S	VACANT	0.01	<0.01	0.16	0.01	0.17
Mosquito Ridge	S	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Limekiln-Sugarloaf	S	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01

Table S3b. Estimated probabilities and annual contact rates for the Manson bighorn sheep herd relative to all existing allotments on the Okanogan-Wenatchee National Forest. This includes cattle, sheep, and horse as well as active and vacant allotments. Information is for illustrative purposes and demonstrates risk if allotments were converted to sheep grazing.

**TELEMETRY
CHHR**

Allotment	Type	Status	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Buttermilk	NA	VACANT	0.01	<0.01	0.31	0.02	0.34
Hunter-McFarland	C	ACTIVE	0.01	<0.01	0.31	0.03	0.34
Union Valley	C	ACTIVE	0.01	<0.01	0.29	0.04	0.33
Horsethief	S	VACANT	0.01	<0.01	0.20	0.02	0.21
Round Mountain	NA	VACANT	0.01	<0.01	0.17	0.02	0.19
Potato Creek	C	ACTIVE	<0.01	<0.01	0.10	0.01	0.11
Antoine Creek	C	ACTIVE	<0.01	<0.01	0.08	<0.01	0.08
Slide Ridge	NA	VACANT	<0.01	<0.01	0.07	0.01	0.08
Alta Coulee	C	ACTIVE	<0.01	<0.01	0.05	<0.01	0.06
Railroad Creek	NA	VACANT	<0.01	<0.01	0.05	<0.01	0.05
Rock Creek	NA	VACANT	<0.01	<0.01	0.04	<0.01	0.04
Hungry	C	ACTIVE	<0.01	<0.01	0.03	<0.01	0.03
Lookout Mountain	C	ACTIVE	0.00	<0.01	0.03	0.00	0.03
Mosquito Ridge	S	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Texas	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
White River	NA	VACANT	<0.01	<0.01	0.01	<0.01	0.01
Benson	C	ACTIVE	<0.01	<0.01	0.00	<0.01	<0.01
Finley	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Limekiln-Sugarloaf	S	ACTIVE	0.00	<0.01	<0.01	<0.01	<0.01
Little Bridge	C	ACTIVE	0.00	<0.01	<0.01	<0.01	<0.01
Squaw Gulch	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
McFarland	C	VACANT					*intersects

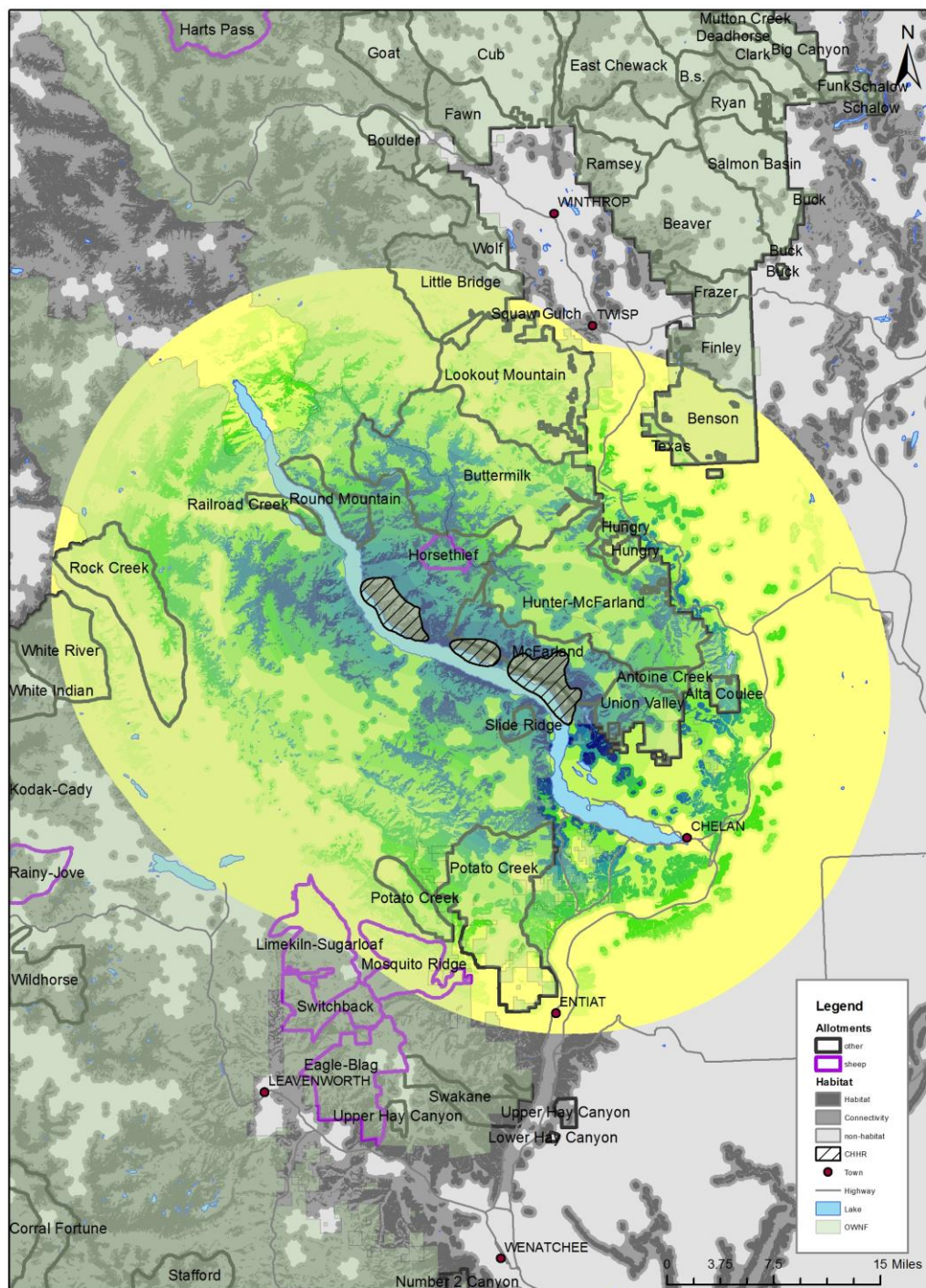
WDFW CHHR

Allotment	Type	Status	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Hunter-McFarland	C	ACTIVE	0.01	<0.01	0.31	0.03	0.34
Union Valley	C	ACTIVE	0.01	<0.01	0.23	0.03	0.27
Buttermilk	NA	VACANT	0.01	<0.01	0.24	0.02	0.26
Round Mountain	NA	VACANT	0.01	<0.01	0.16	0.02	0.18
Horsethief	S	VACANT	0.01	<0.01	0.16	0.01	0.17
Potato Creek	C	ACTIVE	<0.01	<0.01	0.09	0.01	0.10
Slide Ridge	NA	VACANT	<0.01	<0.01	0.07	0.01	0.09
Antoine Creek	C	ACTIVE	<0.01	<0.01	0.07	<0.01	0.08
Alta Coulee	C	ACTIVE	<0.01	<0.01	0.06	0.01	0.06
Railroad Creek	NA	VACANT	<0.01	<0.01	0.04	<0.01	0.05
Rock Creek	NA	VACANT	<0.01	<0.01	0.04	<0.01	0.05
Hungry	C	ACTIVE	<0.01	<0.01	0.03	0.00	0.03
Lookout Mountain	C	ACTIVE	<0.01	<0.01	0.02	0.00	0.03
Mosquito Ridge	S	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Texas	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
White River	NA	VACANT	<0.01	<0.01	0.01	<0.01	0.01
Benson	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Finley	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Limekiln-Sugarloaf	S	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Little Bridge	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
McFarland	C	VACANT					*intersects

* This allotment intersects the home range polygon and is therefore not included in the analysis.

Figure S3. Spatial results generated with the *Bighorn Sheep Risk of Contact Tool* for the Manson bighorn sheep herd. The telemetry core herd home range and WDFW core herd home range for the Manson herd are presented in relation to the domestic grazing allotments, bighorn sheep habitat and foray probabilities for rams, within 35 km of the bighorn home ranges. Foray probability is displayed as concentric rings, with a light yellow indicating low probability of foray and increasing in shade to dark blue, indicating a high probability of foray.

Manson Telemetry CHHR



Manson WDFW CHHR

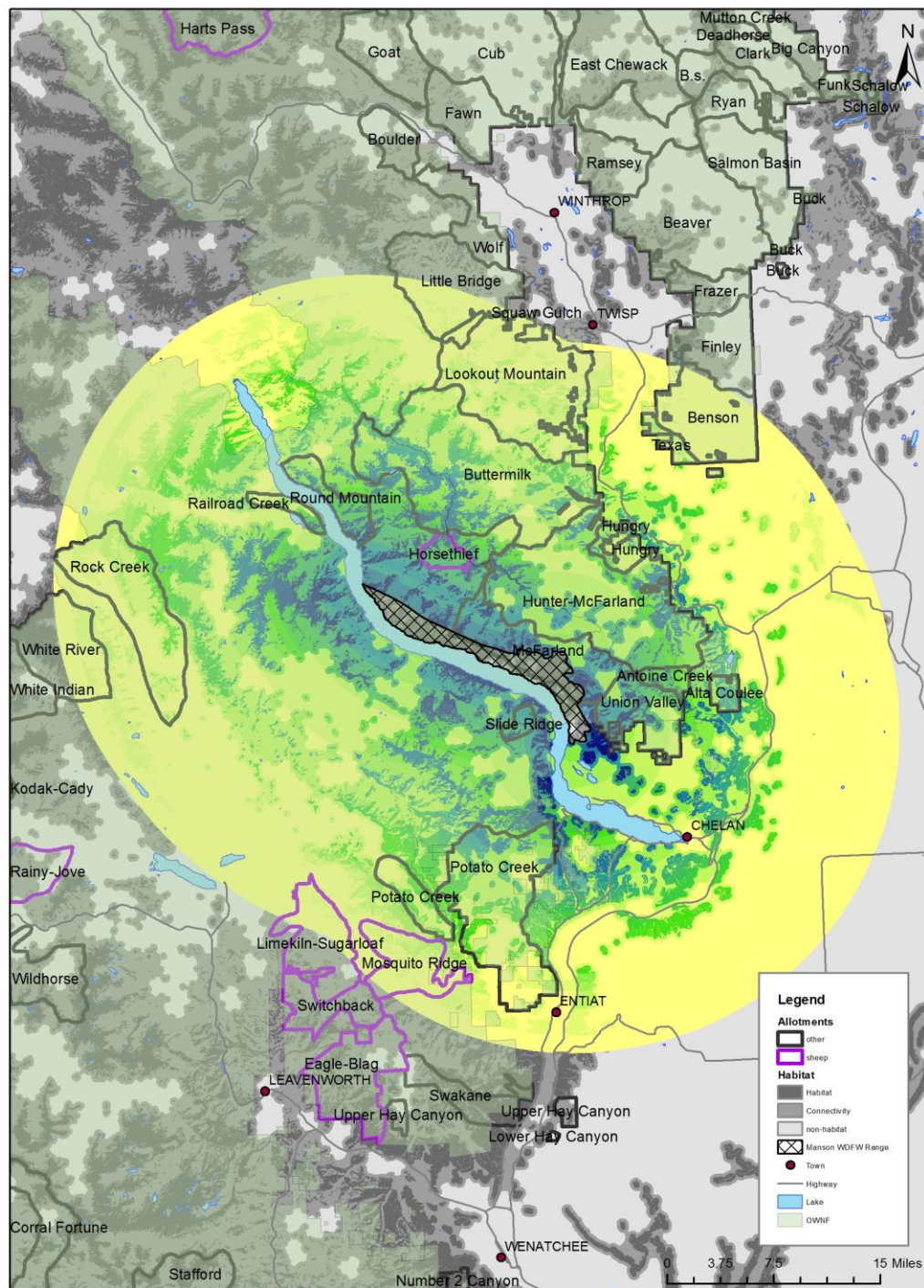


Table S4a. Estimated probabilities and annual contact rates for the Mt. Hull bighorn sheep herd relative to existing **sheep** allotments on the Okanogan-Wenatchee National Forest. Probabilities and contact rates were only estimated for the observed core herd home range delimited by WDFW biologists (WDFW CHHR) as telemetry information was not available.

**MT HULL
WDFW CHHR**

Allotment	Type	Status	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Horseshoe	S	VACANT	<0.01	<0.01	<0.01	<0.01	<0.01

Table S4b. Estimated probabilities and annual contact rates for the Mt. Hull bighorn sheep herd relative to all existing allotments on the Okanogan-Wenatchee National Forest. This includes cattle, sheep, and horse as well as active and vacant allotments. Information is for illustrative purposes and demonstrates risk if allotments were converted to sheep grazing.

WDFW CHHR

Allotment	Type	Status	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Haley	C	ACTIVE	0.01	<0.01	0.25	0.02	0.27
Phoebe	C	ACTIVE	<0.01	<0.01	0.20	0.01	0.21
Island	H	VACANT	<0.01	<0.01	0.16	0.01	0.17
Siwash	C	ACTIVE	<0.01	<0.01	0.09	<0.01	0.09
Cayuse	C	ACTIVE	<0.01	<0.01	0.07	<0.01	0.07
Strawberry	C	ACTIVE	<0.01	<0.01	0.05	<0.01	0.05
Beth	C	ACTIVE	<0.01	<0.01	0.02	<0.01	0.02
Cumberland	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.02
Annie	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Bannon	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Cedar	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Ethel	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Gold	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	0.01
Lost	C	ACTIVE	<0.01	<0.01	0.01	0.00	0.01
Big Canyon	C	ACTIVE	<0.01	<0.01	0.00	<0.01	<0.01
Bodie	C	ACTIVE	<0.01	<0.01	0.00	<0.01	<0.01
Aeneas	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Frosty	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Goodenough	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Horseshoe	S	VACANT	<0.01	<0.01	<0.01	<0.01	<0.01
Revis	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Richwood	C	VACANT	<0.01	<0.01	<0.01	<0.01	<0.01
Schalow	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Sheridan	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Toats Coulee	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Toroda	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Tunk	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Wauconda	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Hull	C	ACTIVE					*intersects

* This allotment intersects the home range polygon and is therefore not included in the analysis.

Figure S4. Spatial results generated with the *Bighorn Sheep Risk of Contact Tool* for the Mt. Hull bighorn sheep herd. The WDFW core herd home range for the Mt. Hull herd is presented in relation to the domestic grazing allotments, bighorn sheep habitat and foray probabilities for rams, within 35 km of the bighorn home ranges. Foray probability is displayed as concentric rings, with a light yellow indicating low probability of foray and increasing in shade to dark blue, indicating a high probability of foray.

Mt Hull WDFW CHHR

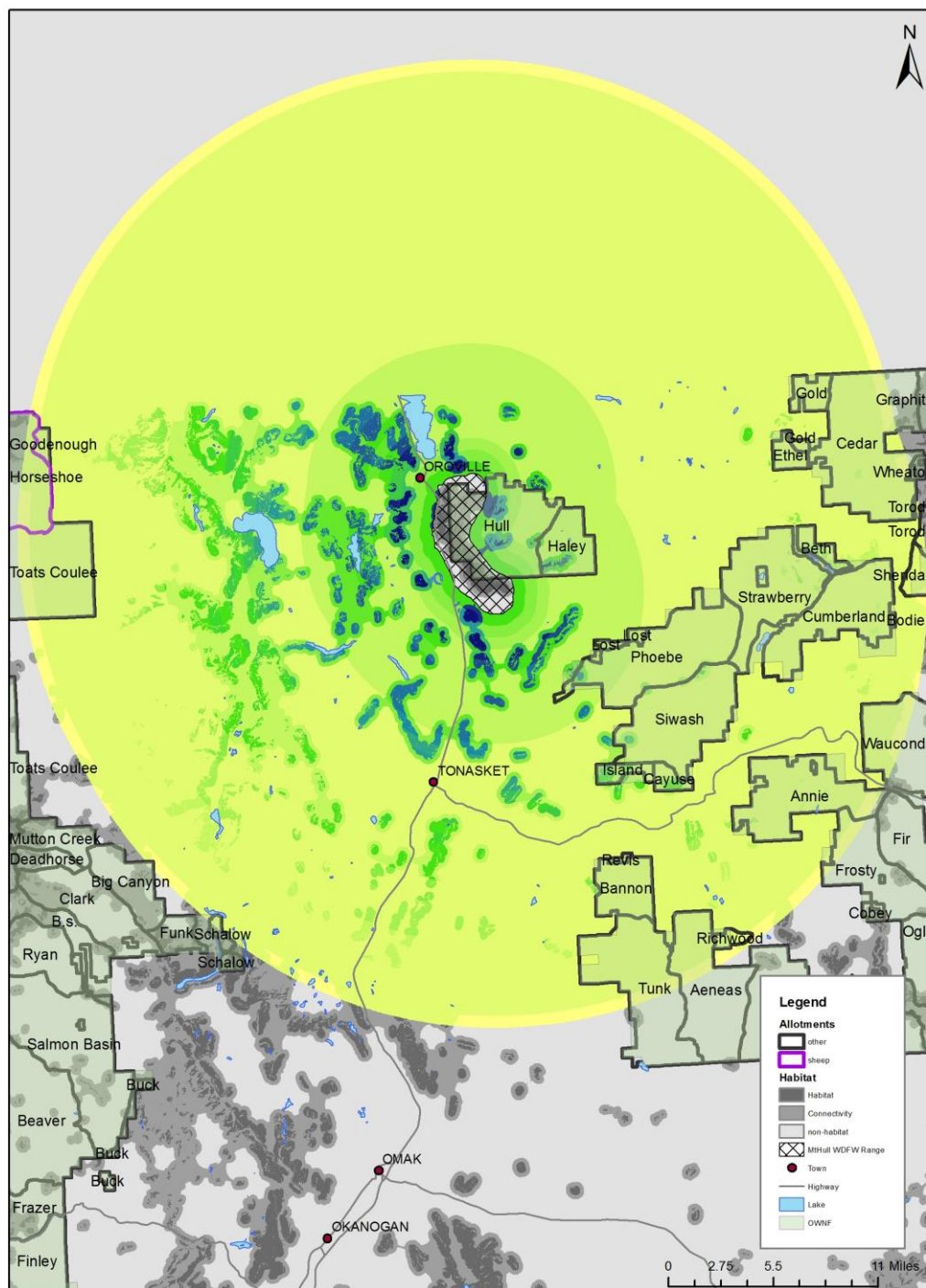


Table S5a. Estimated probabilities and annual contact rates for the Quilomene bighorn sheep herd relative to existing **sheep** allotments on the Okanogan-Wenatchee National Forest. Probabilities and contact rates were estimated for a telemetry derived core herd home range (Telemetry CHHR) and an observed core herd home range delimited by WDFW biologists (WDFW CHHR).

**QUILOMENE
TELEMETRY
CHHR**

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Eagle-Blagg	S	ACTIVE	<0.01	<0.01	<0.01	<0.01	0.01
Swauk	S	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01

WDFW CHHR

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Eagle-Blagg	S	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Swauk	S	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01

Table S5b. Estimated probabilities and annual contact rates for the Quilomene bighorn sheep herd relative to all existing allotments on the Okanogan-Wenatchee National Forest. This includes cattle, sheep, and horse as well as active and vacant allotments. Information is for illustrative purposes and demonstrates risk if allotments were converted to sheep grazing.

**TELEMETRY
CHHR**

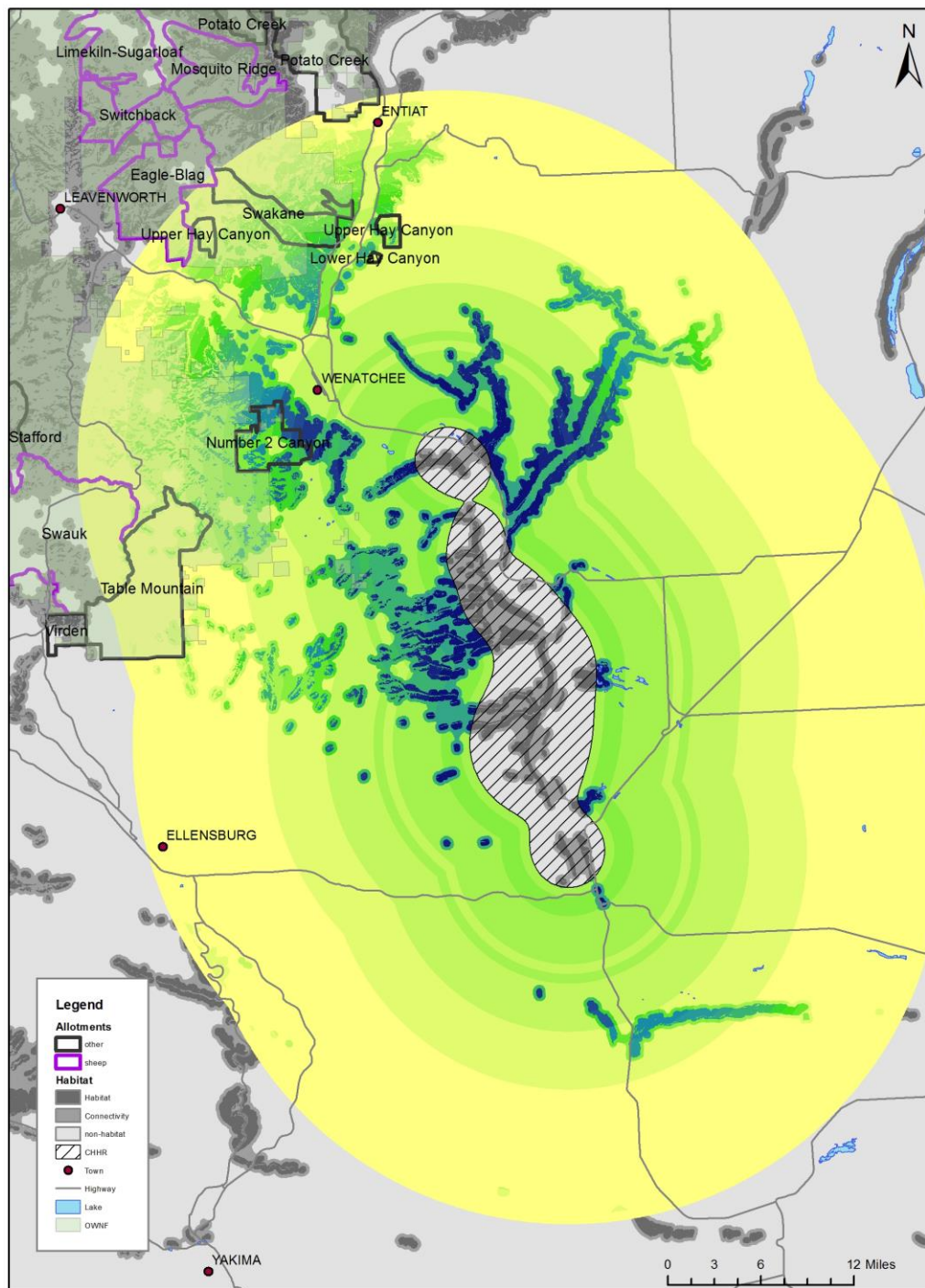
Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Number 2 Canyon	C	ACTIVE	0.01	0.00	0.19	0.01	0.20
Swakane	NA	VACANT	<0.01	<0.01	0.07	<0.01	0.07
Upper Hay Canyon	NA	VACANT	<0.01	<0.01	0.02	<0.01	0.02
Eagle-Blagg	S	ACTIVE	<0.01	<0.01	<0.01	<0.01	0.01
Table Mountain	NA	VACANT	<0.01	<0.01	0.01	<0.01	0.01
Lower Hay Canyon	NA	VACANT	<0.01	<0.01	<0.01	<0.01	<0.01
Potato Creek	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Swauk	S	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01

WDFW CHHR

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Number 2 Canyon	C	ACTIVE	0.01	<0.01	0.27	0.01	0.28
Swakane	NA	VACANT	<0.01	<0.01	0.06	<0.01	0.06
Table Mountain	NA	VACANT	<0.01	<0.01	0.02	<0.01	0.02
Swauk	S	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Upper Hay Canyon	NA	VACANT	<0.01	<0.01	0.01	<0.01	0.01
Eagle-Blagg	S	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Lower Hay Canyon	NA	VACANT	<0.01	<0.01	<0.01	<0.01	<0.01
Potato Creek	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Virden	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01

Figure S5. Spatial results generated with the *Bighorn Sheep Risk of Contact Tool* for the Quilomene bighorn sheep herd. The telemetry core herd home range and WDFW core herd home range for the Quilomene herd are presented in relation to the domestic grazing allotments, bighorn sheep habitat and foray probabilities for rams, within 35 km of the bighorn home ranges. Foray probability is displayed as concentric rings, with a light yellow indicating low probability of foray and increasing in shade to dark blue, indicating a high probability of foray.

Quilomene Telemetry CHHR



Quilomene WDFW CHHR

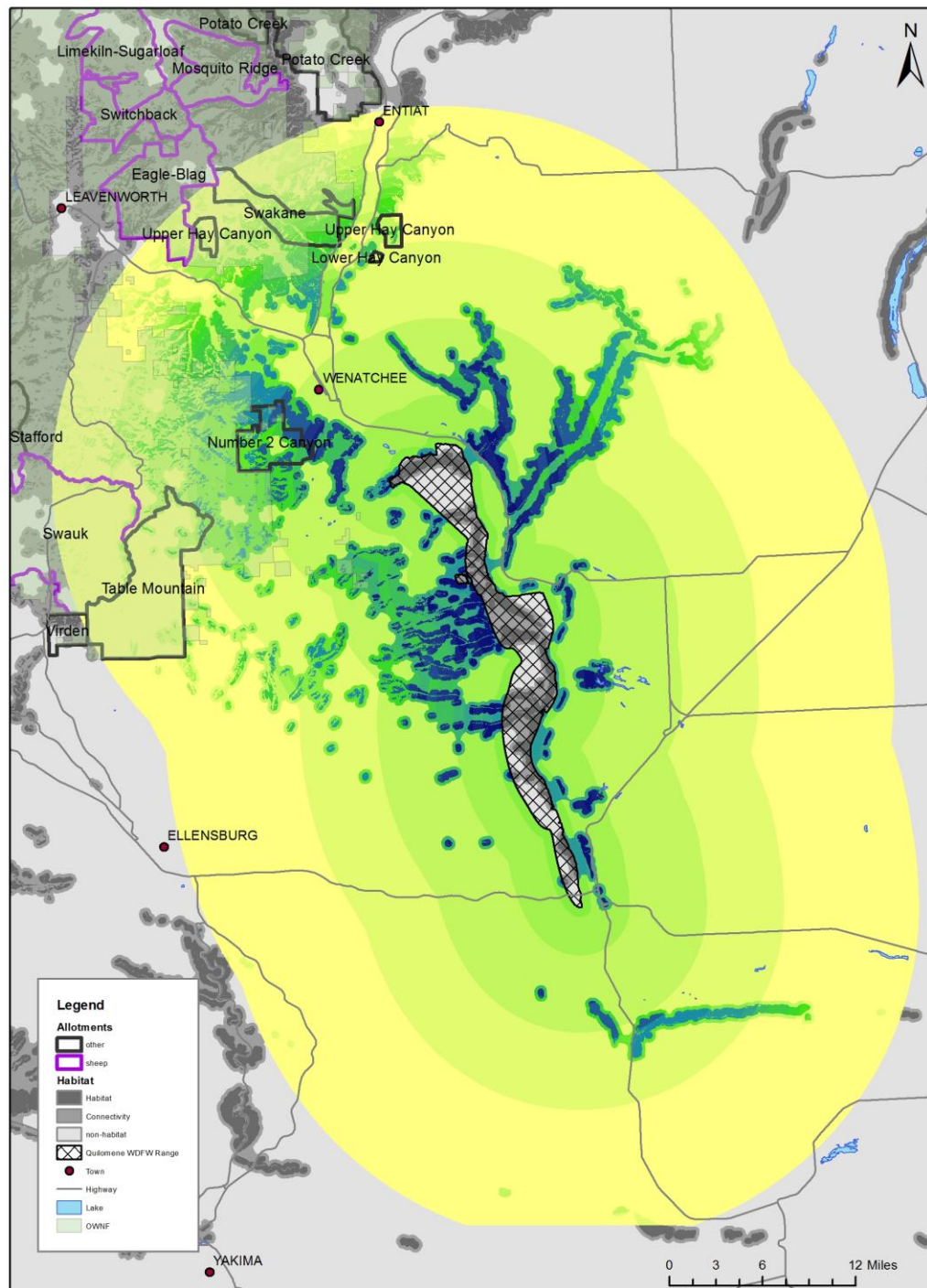


Table S6a. Estimated probabilities and annual contact rates for the Sinlahekin bighorn sheep herd relative to existing **sheep** allotments on the Okanogan-Wenatchee National Forest. Probabilities and contact rates were estimated for a telemetry derived core herd home range (Telemetry CHHR) and an observed core herd home range delimited by WDFW biologists (WDFW CHHR).

**SINLAHEKIN
TELEMETRY
CHHR**

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Horseshoe	S	VACANT	0.01	<0.01	0.24	0.01	0.24

WDFW CHHR

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Horseshoe	S	VACANT	0.01	<0.01	0.04	0.01	0.05

Table S6b. Estimated probabilities and annual contact rates for the Sinlahekin bighorn sheep herd relative to all existing allotments on the Okanogan-Wenatchee National Forest. This includes cattle, sheep, and horse as well as active and vacant allotments. Information is for illustrative purposes and demonstrates risk if allotments were converted to sheep grazing.

**TELEMETRY
CHHR**

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Funk	C	ACTIVE	0.01	<0.01	0.29	0.01	0.29
Horseshoe	S	VACANT	0.01	<0.01	0.24	<0.01	0.24
Big Canyon	C	ACTIVE	0.01	<0.01	0.22	<0.01	0.22
Hull	C	ACTIVE	<0.01	<0.01	0.20	<0.01	0.20
Clark	C	ACTIVE	<0.01	<0.01	0.16	<0.01	0.16
Schalow	C	ACTIVE	<0.01	<0.01	0.16	<0.01	0.16
Mutton Creek	C	ACTIVE	<0.01	<0.01	0.13	<0.01	0.14
Goodenough	C	ACTIVE	<0.01	<0.01	0.10	<0.01	0.10
Fish Coulee	C	ACTIVE	<0.01	<0.01	0.09	<0.01	0.09
Salmon Basin	C	ACTIVE	<0.01	<0.01	0.09	<0.01	0.09
Ryan	C	ACTIVE	<0.01	<0.01	0.08	<0.01	0.08
Toats Coulee	C	ACTIVE	<0.01	<0.01	0.08	<0.01	0.08
B.S.	C	ACTIVE	<0.01	<0.01	0.07	<0.01	0.07
East Chewack	C	ACTIVE	<0.01	<0.01	0.07	<0.01	0.07
Deadhorse	C	ACTIVE	<0.01	<0.01	0.06	<0.01	0.06
Beaver	C	ACTIVE	<0.01	<0.01	0.03	0.01	0.03
Haley	C	ACTIVE	<0.01	<0.01	0.03	<0.01	0.03
Island	H	VACANT	<0.01	<0.01	0.03	<0.01	0.03
Buck	C	ACTIVE	<0.01	<0.01	0.02	<0.01	0.02
Phoebe	C	ACTIVE	<0.01	<0.01	0.02	<0.01	0.02
Frazer	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Ramsey	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Siwash	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Bannon	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Cayuse	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01

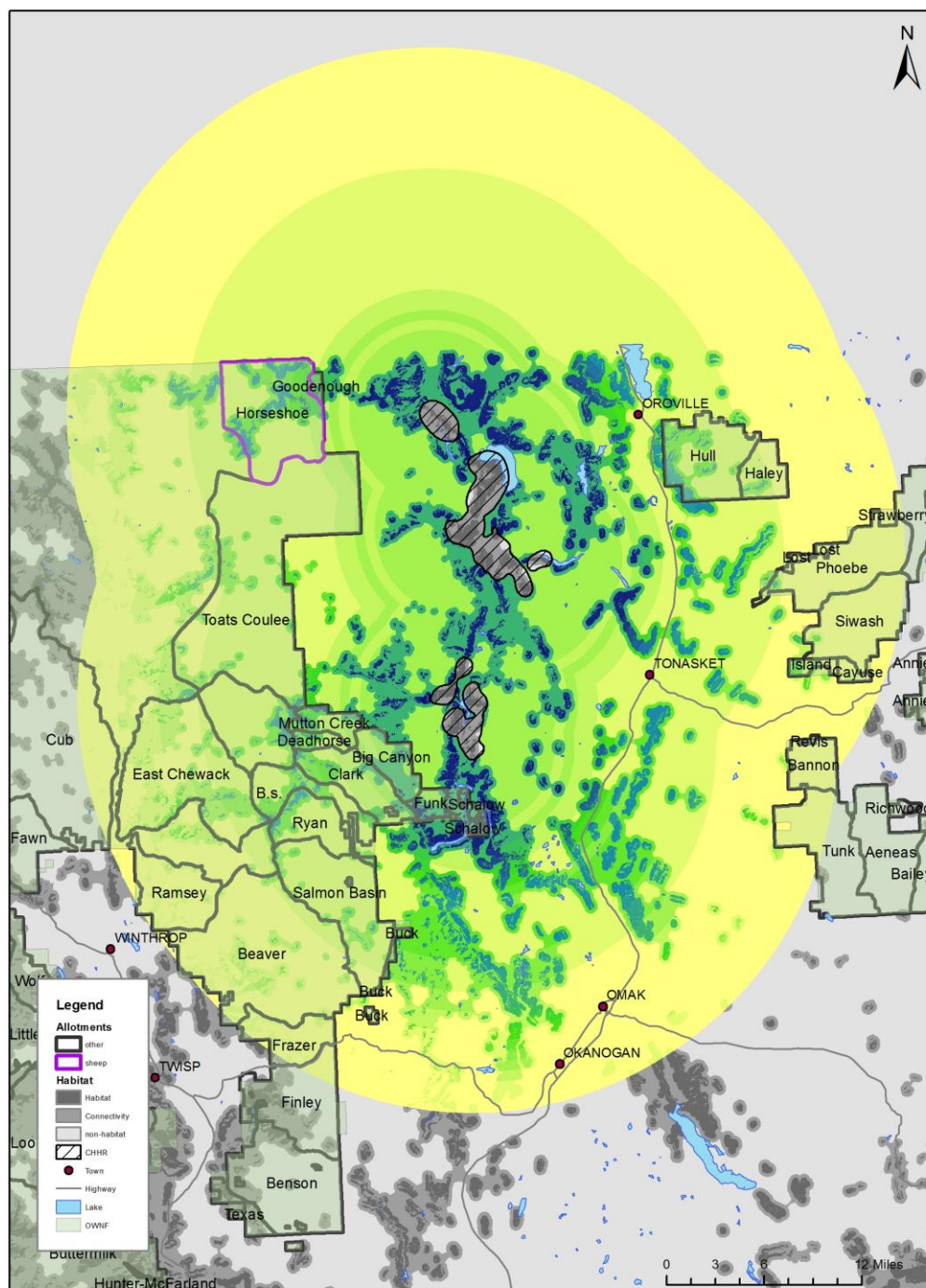
Cub	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Finley	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Lost	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Revis	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Strawberry	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Tunk	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01

WDFW CHHR

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Horseshoe	S	VACANT	0.01	<0.01	0.04	0.01	0.05
Big Canyon	C	ACTIVE	0.01	<0.01	0.03	0.01	0.04
Funk	C	ACTIVE	0.01	<0.01	0.03	0.01	0.04
Schalow	C	ACTIVE	<0.01	<0.01	0.02	0.02	0.04
Hull	C	ACTIVE	0.01	<0.01	0.03	0.01	0.03
Clark	C	ACTIVE	<0.01	<0.01	0.02	<0.01	0.02
Fish Coulee	C	ACTIVE	<0.01	<0.01	0.01	0.01	0.02
Mutton Creek	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.02
Toats Coulee	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.02
B.S.	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Deadhorse	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
East Chewack	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Goodenough	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Ryan	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Salmon Basin	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Beaver	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	0.01
Haley	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	0.01
Island	H	VACANT	<0.01	<0.01	<0.01	<0.01	0.01
Bannon	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Buck	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Cayuse	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Cub	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Finley	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Frazer	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Lost	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Phoebe	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Ramsey	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Revis	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Siwash	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Strawberry	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Tunk	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01

Figure S6. Spatial results generated with the *Bighorn Sheep Risk of Contact Tool* for the Sinlahekin bighorn sheep herd. The telemetry core herd home range and WDFW core herd home range for the Sinlahekin herd are presented in relation to the domestic grazing allotments, bighorn sheep habitat and foray probabilities for rams, within 35 km of the bighorn home ranges. Foray probability is displayed as concentric rings, with a light yellow indicating low probability of foray and increasing in shade to dark blue, indicating a high probability of foray.

Sinlahekin Telemetry CHHR



Sinlahekin WDFW CHHR

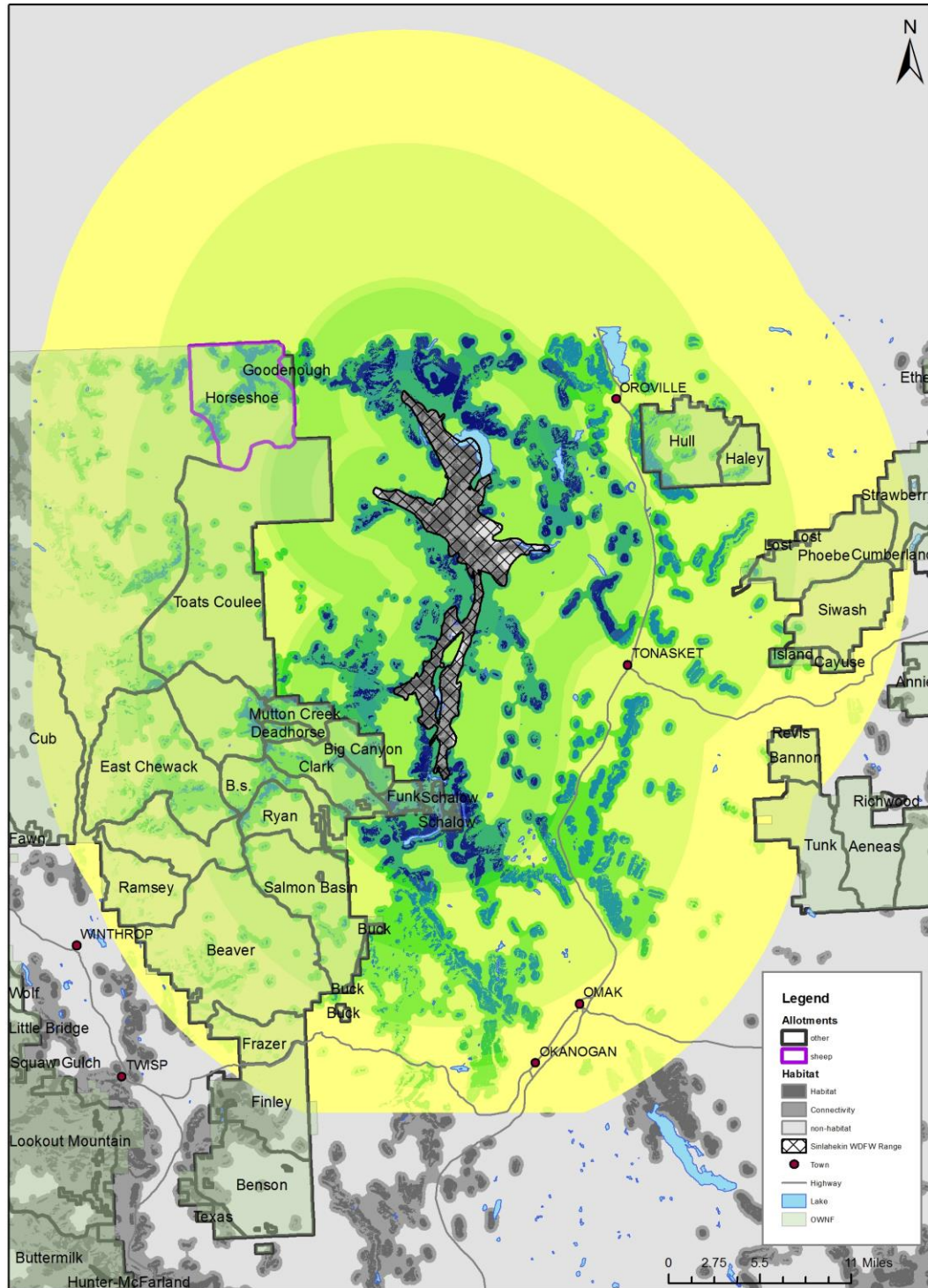


Table S7a. Estimated probabilities and annual contact rates for the Swakane bighorn sheep herd relative to existing **sheep** allotments on the Okanogan-Wenatchee National Forest. Probabilities and contact rates were estimated for a telemetry derived core herd home range (Telemetry CHHR) and an observed core herd home range delimited by WDFW biologists (WDFW CHHR).

**SWAKANE
TELEMETRY
CHHR**

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Eagle-Blagg	S	ACTIVE	0.02	<0.01	0.81	0.03	0.84
Mosquito Ridge	S	ACTIVE	<0.01	<0.01	0.21	0.01	0.22
Switchback	S	ACTIVE	<0.01	<0.01	0.11	<0.01	0.11
Limekiln-Sugarloaf	S	ACTIVE	<0.01	<0.01	0.05	<0.01	0.05
Swauk	S	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01

WDFW CHHR

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Eagle-Blagg	S	ACTIVE	0.02	<0.01	0.74	0.03	0.77
Mosquito Ridge	S	ACTIVE	0.01	<0.01	0.23	0.01	0.24
Switchback	S	ACTIVE	<0.01	<0.01	0.13	<0.01	0.13
Limekiln-Sugarloaf	S	ACTIVE	<0.01	<0.01	0.06	<0.01	0.06
Swauk	S	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01

Table S7b. Estimated probabilities and annual contact rates for the Swakane bighorn sheep herd relative to all existing allotments on the Okanogan-Wenatchee National Forest. This includes cattle, sheep, and horse as well as active and vacant allotments. Information is for illustrative purposes and demonstrates risk if allotments were converted to sheep grazing.

**TELEMETRY
CHHR**

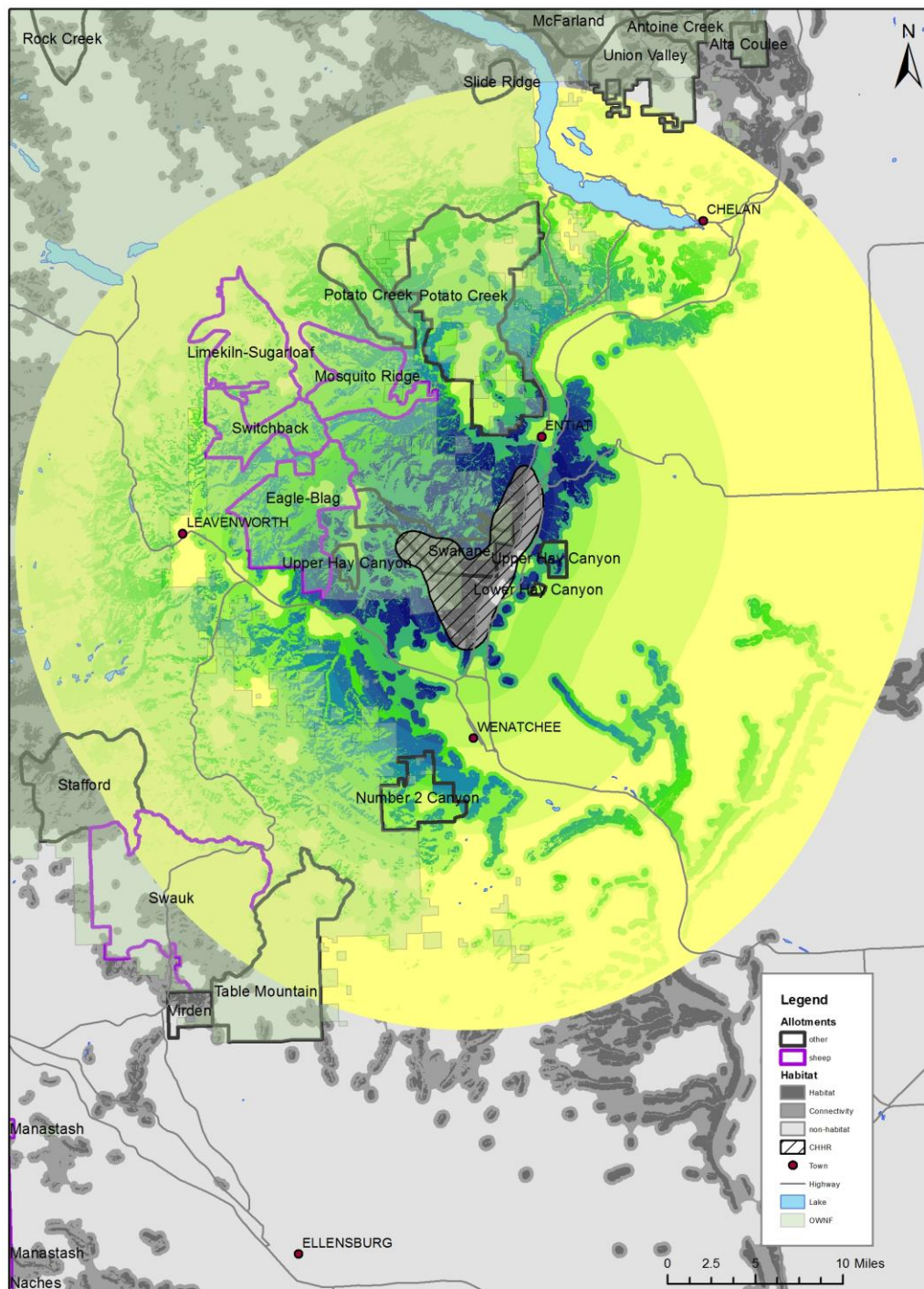
Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Eagle-Blagg	S	ACTIVE	0.02	<0.01	0.81	0.03	0.84
Potato Creek	C	ACTIVE	0.01	<0.01	0.33	0.02	0.36
Upper Hay Canyon	NA	VACANT	0.01	<0.01	0.26	0.02	0.27
Mosquito Ridge	S	ACTIVE	<0.01	<0.01	0.21	0.01	0.22
Number 2 Canyon	C	ACTIVE	<0.01	<0.01	0.20	0.01	0.21
Switchback	S	ACTIVE	<0.01	<0.01	0.11	<0.01	0.11
Limekiln-Sugarloaf	S	ACTIVE	<0.01	<0.01	0.05	<0.01	0.05
Lower Hay Canyon	NA	VACANT	<0.01	<0.01	0.01	<0.01	0.02
Stafford	NA	VACANT	<0.01	<0.01	0.01	<0.01	0.01
Swauk	S	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Table Mountain	NA	VACANT	<0.01	<0.01	0.01	<0.01	0.01
Slide Ridge	NA	VACANT	<0.01	<0.01	<0.01	<0.01	<0.01
Union Valley	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Swakane	NA	VACANT					*intersects

WDFW CHHR

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Eagle-Blagg	S	ACTIVE	0.02	<0.01	0.74	0.03	0.77
Potato Creek	C	ACTIVE	0.01	<0.01	0.45	0.04	0.49
Upper Hay Canyon	NA	VACANT	0.01	<0.01	0.38	0.03	0.41
Number 2 Canyon	C	ACTIVE	0.01	<0.01	0.27	0.01	0.28
Mosquito Ridge	S	ACTIVE	0.01	<0.01	0.23	0.01	0.24
Switchback	S	ACTIVE	<0.01	<0.01	0.13	<0.01	0.13
Limekiln-Sugarloaf	S	ACTIVE	<0.01	<0.01	0.06	<0.01	0.06
Table Mountain	NA	VACANT	<0.01	<0.01	0.02	<0.01	0.02
Lower Hay Canyon	NA	VACANT	<0.01	<0.01	0.01	<0.01	0.01
Stafford	NA	VACANT	<0.01	<0.01	0.01	<0.01	0.01
Swauk	S	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Slide Ridge	NA	VACANT	<0.01	<0.01	<0.01	<0.01	<0.01
Union Valley	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Swakane	NA	VACANT					*intersects

Figure S7. Spatial results generated with the *Bighorn Sheep Risk of Contact Tool* for the Swakane bighorn sheep herd. The Telemetry core herd home range and WDFW core herd home range for the Swakane herd are presented in relation to the domestic grazing allotments, bighorn sheep habitat and foray probabilities for rams, within 35 km of the bighorn home ranges. Foray probability is displayed as concentric rings, with a light yellow indicating low probability of foray and increasing in shade to dark blue, indicating a high probability of foray.

Swakane Telemetry CHHR



Swakane WDFW CHHR

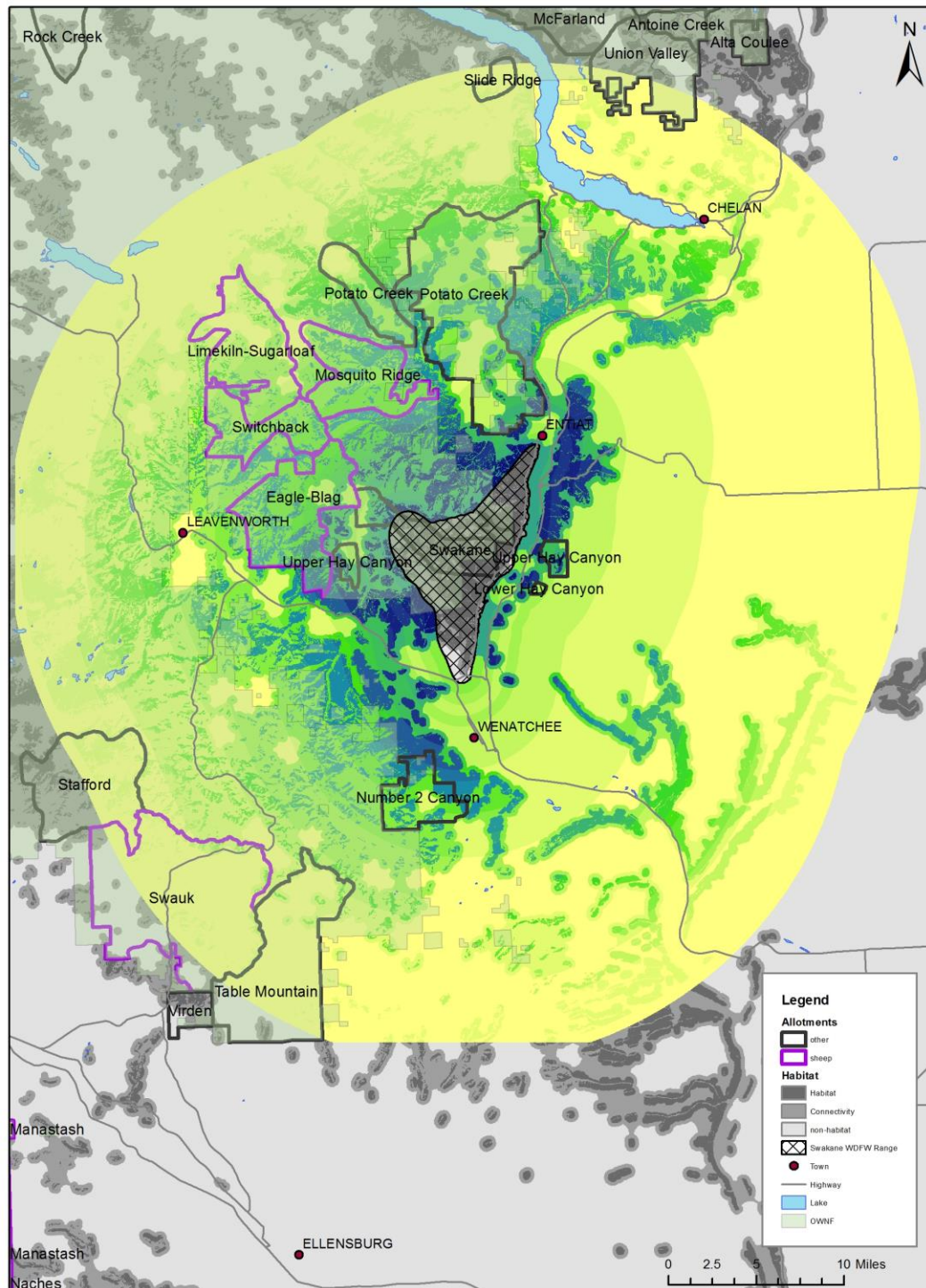


Table S8a. Estimated probabilities and annual contact rates for the Tieton bighorn sheep herd relative to existing **sheep** allotments on the Okanogan-Wenatchee National Forest. Probabilities and contact rates were estimated for a telemetry derived core herd home range (Telemetry CHHR) and an observed core herd home range delimited by WDFW biologists (WDFW CHHR). The Tieton bighorn herd experienced an all-age die-off in the spring of 2013. The most recent data available for the Tieton herd was from 2010-2013, prior to the die-off and subsequent herd removal. As such, the results presented here only represent hypothetical results based on the previous bighorn herd. *NachesNorth* and *NachesSouth* refer to hypothetical modifications to the Naches allotment based on input from the OWNF.

TIETON**TELEMETRY CHHR**

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
<i>NachesSouth</i>	S	ACTIVE	0.01	<0.01	0.17	0.02	0.19
Naches	S	ACTIVE	0.01	<0.01	0.16	0.02	0.18
Rattlesnake	S	ACTIVE	0.01	<0.01	0.15	0.02	0.17
Nile	S	ACTIVE	0.01	<0.01	0.10	0.01	0.12
<i>NachesNorth</i>	S	ACTIVE	<0.01	<0.01	0.02	<0.01	0.02
Manastash	S	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01

WDFW CHHR

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Naches	S	ACTIVE	0.01	<0.01	0.17	0.04	0.21
<i>NachesSouth</i>	S	ACTIVE	0.01	<0.01	0.17	0.04	0.21
<i>NachesNorth</i>	S	ACTIVE	<0.01	<0.01	0.02	<0.01	0.02
Manastash	S	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01

* This allotment intersects the home range polygon and is therefore not included in the analysis.

Table S8b. Estimated probabilities and annual contact rates for the Tieton bighorn sheep herd relative to all existing allotments on the Okanogan-Wenatchee National Forest. This includes cattle, sheep, and horse as well as active and vacant allotments. Information is for illustrative purposes and demonstrates risk if allotments were converted to sheep grazing.

TELEMETRY CHHR

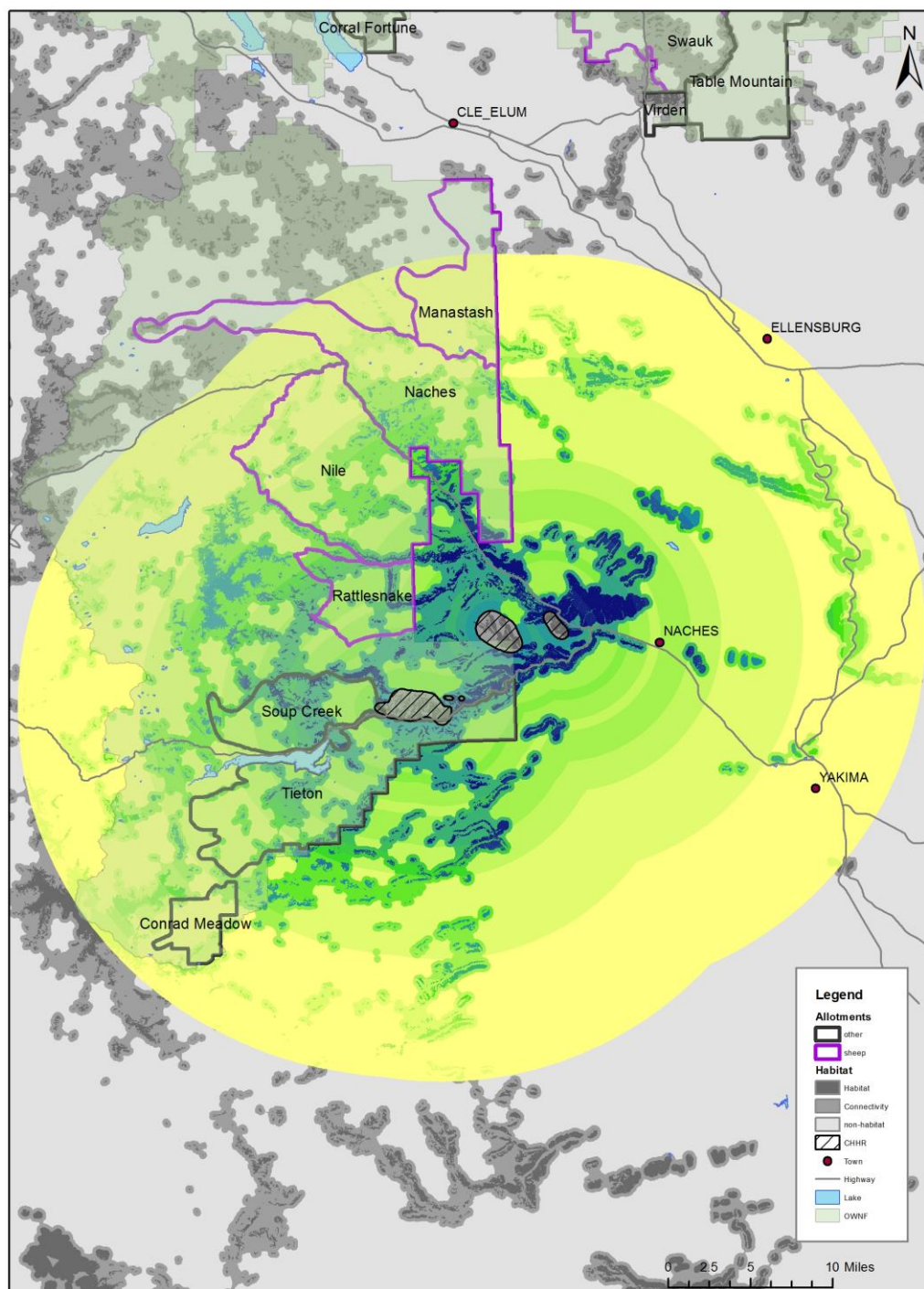
Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Naches	S	ACTIVE	0.01	<0.01	0.16	0.02	0.18
Rattlesnake	S	ACTIVE	0.01	<0.01	0.15	0.02	0.17
Nile	S	ACTIVE	0.01	<0.01	0.10	0.01	0.12
Conrad Meadow	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Manastash	S	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Soup Creek	C	ACTIVE					*intersects
Tieton	C	ACTIVE					*intersects

WDFW CHHR

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Rattlesnake	S	ACTIVE	0.01	<0.01	0.20	0.02	0.22
Naches	S	ACTIVE	0.01	<0.01	0.17	0.04	0.21
Nile	S	ACTIVE	0.01	<0.01	0.11	0.01	0.12
Conrad Meadow	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Manastash	S	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Soup Creek	C	ACTIVE					*intersects
Tieton	C	ACTIVE					*intersects

Figure S8. Spatial results generated with the *Bighorn Sheep Risk of Contact Tool* for the Tieton bighorn sheep herd. The Telemetry core herd home range and WDFW core herd home range for the Tieton herd are presented in relation to the domestic grazing allotments, bighorn sheep habitat and foray probabilities for rams, within 35 km of the bighorn home ranges. Foray probability is displayed as concentric rings, with a light yellow indicating low probability of foray and increasing in shade to dark blue, indicating a high probability of foray.

Tieton Telemetry CHHR



Tieton WDFW CHHR

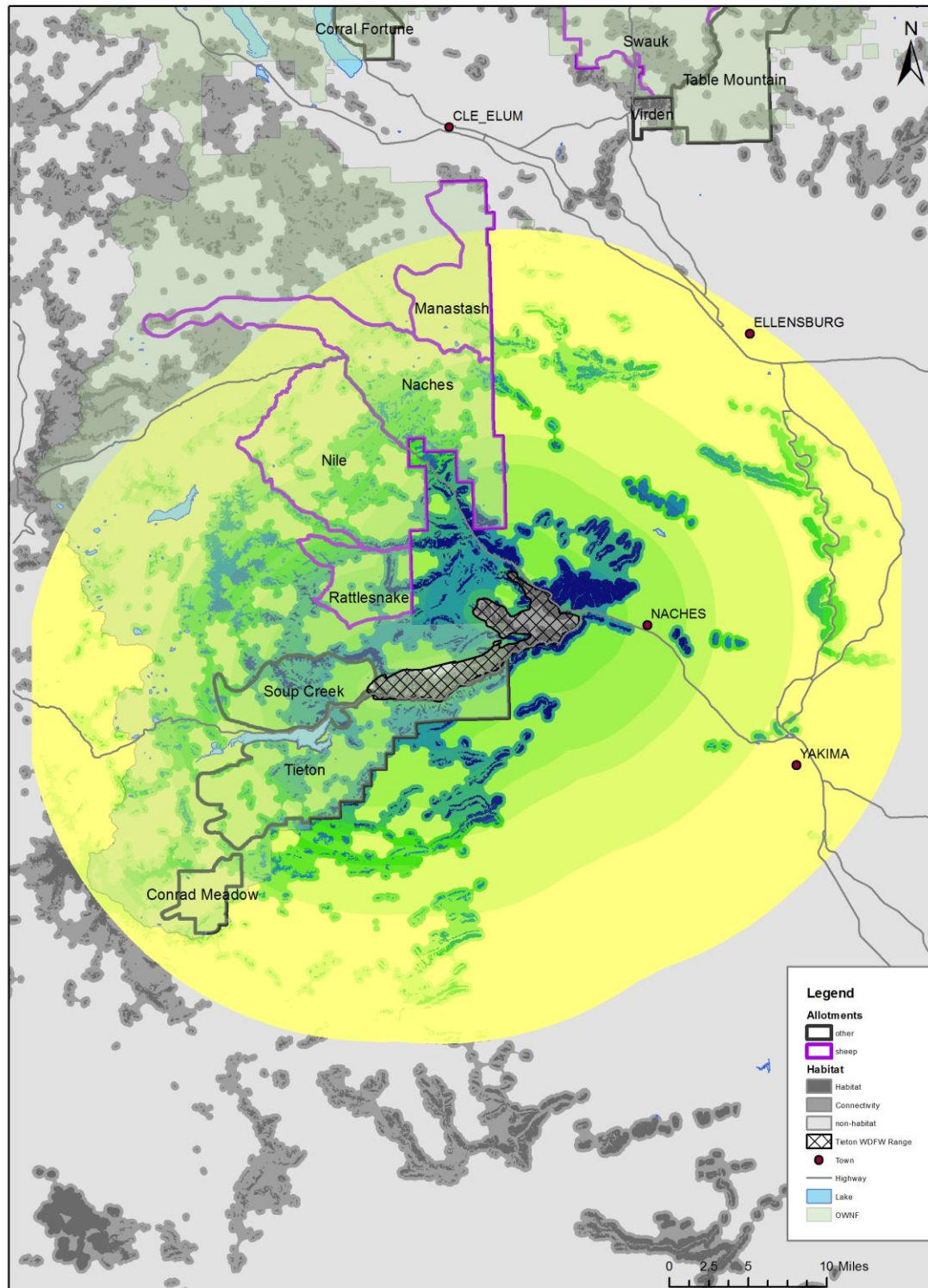


Table S9a. Estimated probabilities and annual contact rates for the Umtanum bighorn sheep herd relative to existing **sheep** allotments on the Okanogan-Wenatchee National Forest. Probabilities and contact rates were estimated for an observed core herd home range delimited by WDFW biologists (WDFW CHHR) as seasonal telemetry data were not available. *NachesNorth* and *NachesSouth* refer to hypothetical modifications to the Naches allotment based on input from the OWNF.

**UMTANUM
WDFW CHHR**

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Naches	S	ACTIVE	0.01	0.01	0.24	0.02	0.26
<i>NachesSouth</i>	S	ACTIVE	0.01	0.01	0.24	0.02	0.26
Manastash	S	ACTIVE	0.01	0.01	0.04	0.01	0.04
Nile	S	ACTIVE	0.01	0.01	0.03	0.01	0.04
Rattlesnake	S	ACTIVE	0.01	0.01	0.03	0.01	0.04
Swauk	S	ACTIVE	0.01	0.01	0.01	0.01	0.01
<i>NachesNorth</i>	S	ACTIVE	0.01	0.01	0.01	0.01	0.01

Table S9b. Estimated probabilities and annual contact rates for the Umtanum bighorn herd relative to all existing allotments on the Okanogan-Wenatchee National Forest. This includes cattle, sheep, and horse as well as active and vacant allotments. Information is for illustrative purposes and demonstrates risk if allotments were converted to sheep grazing.

WDFW CHHR

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Naches	S	ACTIVE	<0.01	<0.01	0.24	0.02	0.26
Tieton	C	ACTIVE	<0.01	<0.01	0.05	<0.01	0.05
Manastash	S	ACTIVE	<0.01	<0.01	0.04	<0.01	0.04
Nile	S	ACTIVE	<0.01	<0.01	0.03	0.01	0.04
Rattlesnake	S	ACTIVE	<0.01	<0.01	0.03	0.01	0.04
Table Mountain	NA	VACANT	<0.01	<0.01	0.01	<0.01	0.02
Virden	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Soup Creek	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Swauk	S	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01

Figure S9. Spatial results generated with the *Bighorn Sheep Risk of Contact Tool* for the Umtanum bighorn sheep herd. The WDFW core herd home range for the Umtanum herd is presented in relation to the domestic grazing allotments, bighorn sheep habitat and foray probabilities for rams, within 35 km of the bighorn home ranges. Foray probability is displayed as concentric rings, with a light yellow indicating low probability of foray and increasing in shade to dark blue, indicating a high probability of foray.

Umtanum WDFW CHHR

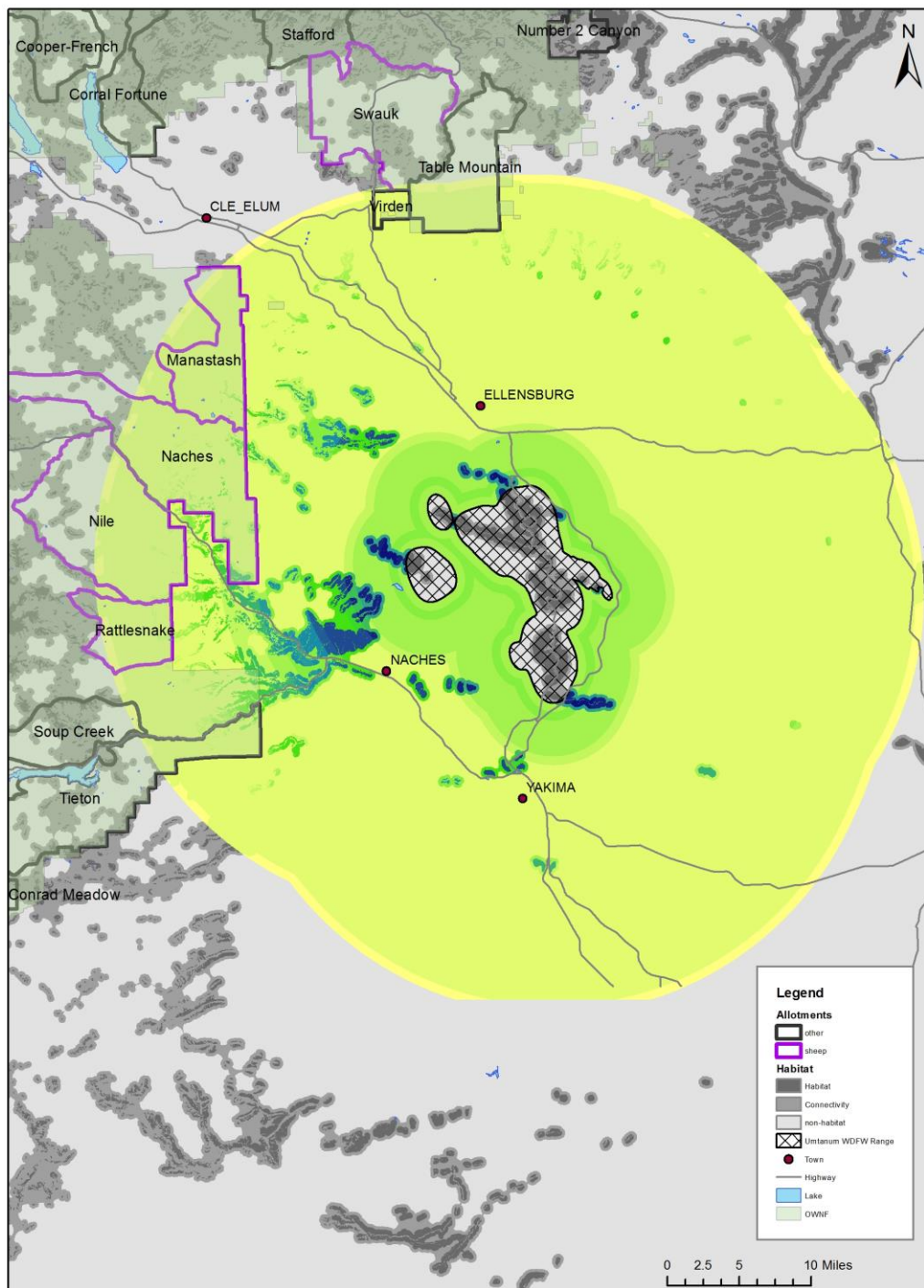


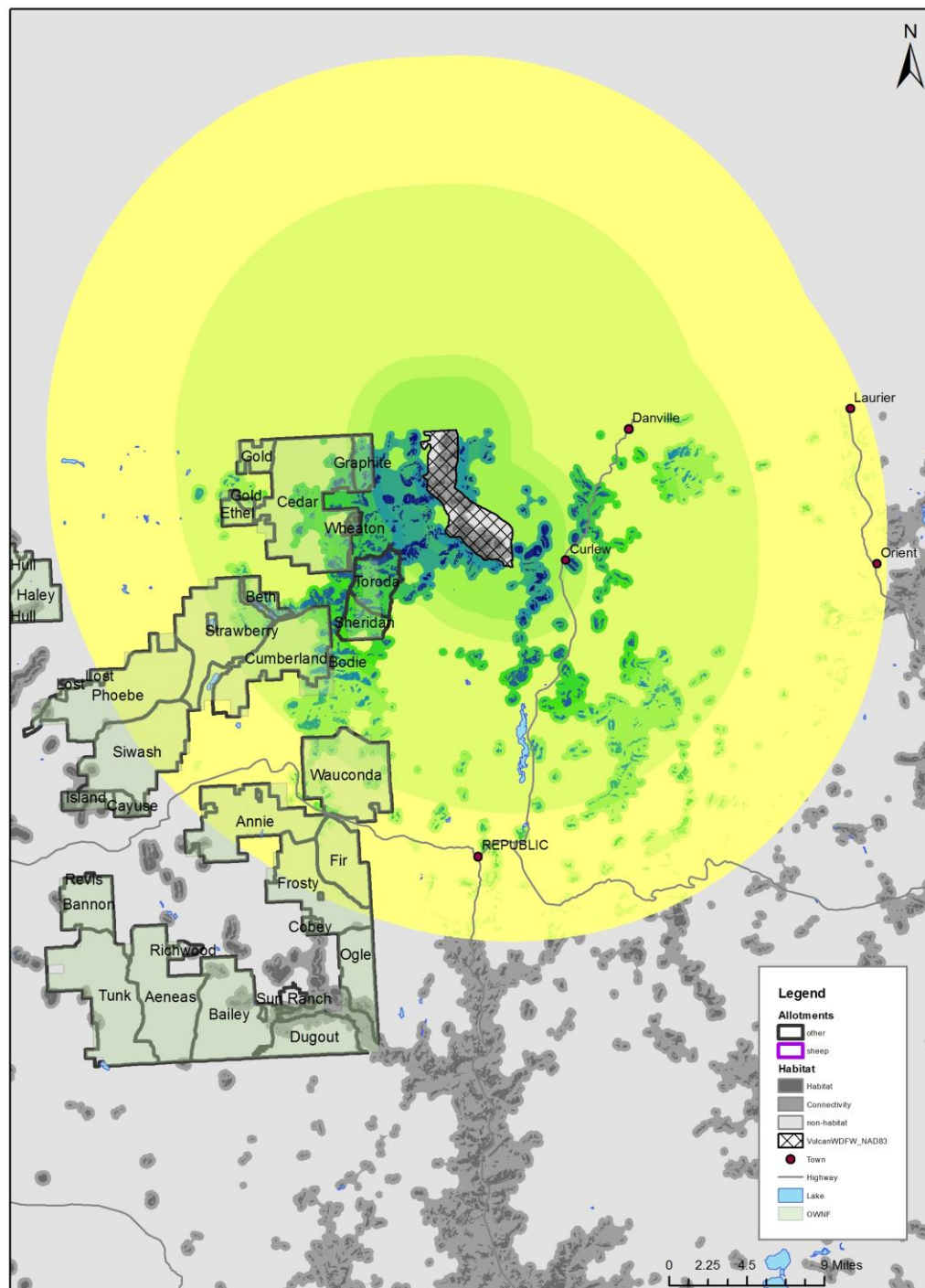
Table S10. Estimated probabilities and annual contact rates for the Vulcan bighorn sheep herd relative to all existing allotments on the Okanogan-Wenatchee National Forest. This includes cattle, sheep, and horse as well as active and vacant allotments. Probabilities and contact rates were only estimated for an observed core herd home range delimited by WDFW biologists (WDFW CHHR) as telemetry data were not available.

VULCAN
WDFW CHHR

Allotment	TYPE	STATUS	Single_Ram	Single_Ewe	All_Rams	All_Ewes	All_Herd
Cedar	C	ACTIVE	0.02	<0.01	0.18	0.01	0.19
Graphite	C	ACTIVE	0.02	<0.01	0.17	0.01	0.19
Toroda	C	ACTIVE	0.02	<0.01	0.17	0.01	0.18
Sheridan	C	ACTIVE	0.01	<0.01	0.10	<0.01	0.10
Wheaton	C	ACTIVE	0.01	<0.01	0.06	<0.01	0.07
Cumberland	C	ACTIVE	<0.01	<0.01	0.05	<0.01	0.05
Beth	C	ACTIVE	<0.01	<0.01	0.03	<0.01	0.03
Strawberry	C	ACTIVE	<0.01	<0.01	0.03	<0.01	0.03
Wauconda	C	ACTIVE	<0.01	<0.01	0.02	<0.01	0.03
Bodie	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Ethel	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Gold	C	ACTIVE	<0.01	<0.01	0.01	<0.01	0.01
Annie	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Fir	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Frosty	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Lost	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Phoebe	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01
Siwash	C	ACTIVE	<0.01	<0.01	<0.01	<0.01	<0.01

Figure S10. Spatial results generated with the *Bighorn Sheep Risk of Contact Tool* for the Vulcan bighorn sheep herd. The WDFW core herd home range for the Vulcan herd is presented in relation to the domestic grazing allotments, bighorn sheep habitat and foray probabilities for rams, within 35 km of the bighorn home ranges. Foray probability is displayed as concentric rings, with a light yellow indicating low probability of foray and increasing in shade to dark blue, indicating a high probability of foray.

Vulcan WDFW CHHR



Appendix S2. Independent reviewer comments.

Reviewer Comment	Response
This is an interesting and potentially useful disease risk analysis for bighorn sheep in the Okanogan-Wenatchee National Forest. I think it helps to answer an important question regarding grazing and wildlife management. In general, the modeling process appears to be sound, but I do have some issues described below that you might address. The presentation in general is good, but I have some suggestions below to make it better. The figures are well done and useful. See my comments below about the tables. My main comments are below, and a number of detailed suggestions are marked in the document file.	Modified report as suggested, including those provided via track changes.
Model	
I suggest you have a short paragraph in the methods to describe how the model works. You describe the components of the model and how they are parameterized, but I had no idea of how that information was tied together to give the results.	For further information see O'Brien et al 2014.
As with any model, the reader should have an idea of the reliability of the model. If I was reading a NEPA analysis of this issue, I would want to know how good the model is in predicting forays and outbreaks. Was the model verified by the developers? You might add something about this either in the introduction or methods sections, or in the discussion relative to applicability to the OWNF. Maybe the discussion would be good to describe the pros and cons of the model as applied to the OWNF.	For further information see O'Brien et al 2014 and the Bighorn Sheep Risk of Contact User Guide.
Presentation	
The format of the results is kind of awkward, with the same paragraph mostly repeated with changes in the herd name and numbers: my eyes glaze over and my mind wanders when confronted with this kind of text. Is there a way to summarize the results for all the herds, note the important results, and refer the reader to the tables for details? For example, if values for many herds fall in the same range, then give that range and list the herds and refer the reader to tables for details. If there are some low or high outliers, then present them. The paragraph you have for Likelihood of Disease Transmission is more like what I'd like to read.	Modified as suggested.
I was not sure what rate of contact you were reporting in the text – All Herds? You have several different rates listed in the tables. Are these rates for telemetry CHRR or the other WDFW CHHR?	We modified text to improve clarity.
Since your results and discussion section are both short, consider combining them into a Results & Discussion section – I think that might flow better.	Modified as suggested.

<p>You have a lot of results in tables that you don't describe in the Results section, e.g., for WDFW CHHR vs. telemetry CHHR, rams vs. ewes, etc.). I suggest extracting the most important results from all the tables, and put them into a couple tables for the results section (Table 3?). That is, if you don't mention a result in the results section (e.g. rates for rams, ewes, etc.) then put those results in an appendix. Make it easy for the reader to understand the significant results.</p>	<p>Modified as suggested.</p>
<p>Maybe have an appendix for each herd with the extended tables and the figures. Perhaps use a figure/map in the results section only for herds with significant risk results.</p>	<p>Modified as suggested.</p>
<p>Table 3 is not cited anywhere in the text that I found, and it seems to repeat information in tables that follow it for each herd? Don't repeat information in the report. Perhaps Table 3 would be the main table in the Results, and the rest of the tables for each herd would be in appendices, where repeating information is OK.</p>	<p>Modified as suggested.</p>
<p>Figures are great. However, usually each figure has a complete description. It is awkward (and annoying) for a reader to look at a figure and not be able to figure it out, if they have not read the caption for the very first figure. I suggest that the caption for each figure allows the reader to interpret the figure without having to search for or page back to another figure. I don't think you have to redo the figures without complete legends, if you explain in the caption what the colors mean.</p>	<p>Modified as suggested.</p>
<p>The table numbering is odd. I think your tables should be numbered e.g. Table 4a and 4b, not Table 4 and 4a.</p>	<p>Modified as suggested.</p>
<p>Table 14 is really the big point of the analysis, yet it is hidden at the end of the report. If you put all the herd tables in appendices and move this table up to a revised Results as maybe Table 2 or 3.</p>	<p>Modified as suggested.</p>